Brown AND Caldwell

701 Pike Street, Suite 1200
Seattle, Washington, 98101
Tel: 206-624-0100
Fax: 206-749-2200

Final Report

Prepared for: King County Department of Natural Resources and Parks

Project Title: Mechanical-Electrical On-Call Services: Grease Study Task Order

Project No: 141326.002.040

Executive Summary

Subject: South Plant Grease Study Final Report

Date: December 22, 2011

To: John Smyth, Project Manager

From: Ian McKelvey, Project Manager

Copy to: Chris Muller, Project Engineer

Prepared by: ______________________________

Christopher Muller, Ph.D., P.E.

Reviewed by: ______________________________

Ian McKelvey, P.E.

1. Introduction

King County Department of Natural Resources and Parks (DNRP) Wastewater Treatment Division's (WTD) published vision is, "Creating Resources from Wastewater." With the completion of the Brightwater Advanced Wastewater Treatment Plant, flows from North Creek and York Pump Stations will be diverted away from South Treatment Plant resulting in increased capacity in the South Plant digesters. One potential use for this additional capacity that would be in line with the WTD's vision statement would be the acceptance of brown grease, the grease collected in grease traps and grease interceptors at food services establishments (FSEs) and food processors, in South Plant's existing digesters.

Brown grease is typically handled as a waste product, often being dewatered and landfilled. Primarily made up of fats, brown grease is of high calorific value and thus energy and can be anaerobically biodegraded to produce biogas just as sewage sludge is currently being digested at South Plant. The addition of brown grease to sewage sludge for co-digestion is not a new practice; wastewater facilities in Riverside, California (East Bay Municipal Utility District), Oxnard, California, Millbrae, California, and Waco, Texas currently co-digest at their wastewater treatment facilities. In the Pacific Northwest, several utilities are either moving toward utilizing brown grease beneficially (Clean Water Services, Oregon, and Metro Vancouver, British Columbia) or have investigated its use (Tacoma, Washington, Medford, Oregon, and Bellingham, Washington).

To investigate the potential ramifications of adding co-digestion to the South Treatment Plant process, an investigation into the available process capacity was performed and a business case evaluation (BCE) was developed to evaluate the financial viability of a conceptual co-digestion facility layout. This report summarizes the findings of these investigations and includes the detailed technical memoranda developed as attachments. In addition, comments from King County staff during review of the facility layout technical memorandum are included as an attachment to aid future detailed design efforts.

2. Capacity Analysis

The capacity of the four existing anaerobic digesters and sludge blend tank at South Plant to accept brown grease is limited by two factors: the organic loading rate and the hydraulic retention time. The organic loading rate is defined as the amount of volatile organics loaded to a unit volume over a specific time period. For grease loading this is limited to 30 percent of the daily sludge load based on best engineering practice. The hydraulic retention time is defined as the active volume divided by flow rate. The hydraulic limit of the digesters at South Plant was defined as a 20 day retention period under all flow and load conditions. This was based on WTD operator experience and to maintain process operating conditions for stable operation and superior biosolids product quality while meeting the United States Environmental Protection Agency's (EPA) requirement of significant pathogen reduction.

The capacity analysis found that the one digester out of service at average annual flows and loads condition dominated the capacity limits for brown grease acceptance. Figure ES-1 and Figure ES-2 were developed for multiple grease mass flow rates and concentrations and show organic loading limits as well as hydraulic limits. Assuming a 30% load fraction and 5% grease concentration, the South Plant digesters have organic loading capacity to 2028 and hydraulic loading capacity to 2020.

Further capacity analysis of biogas end use equipment capacity indicated that the waste gas burners may begin to become limiting in 2024, depending on the operating strategy (number of duty burners) and the level of additional gas production from co-digestion.

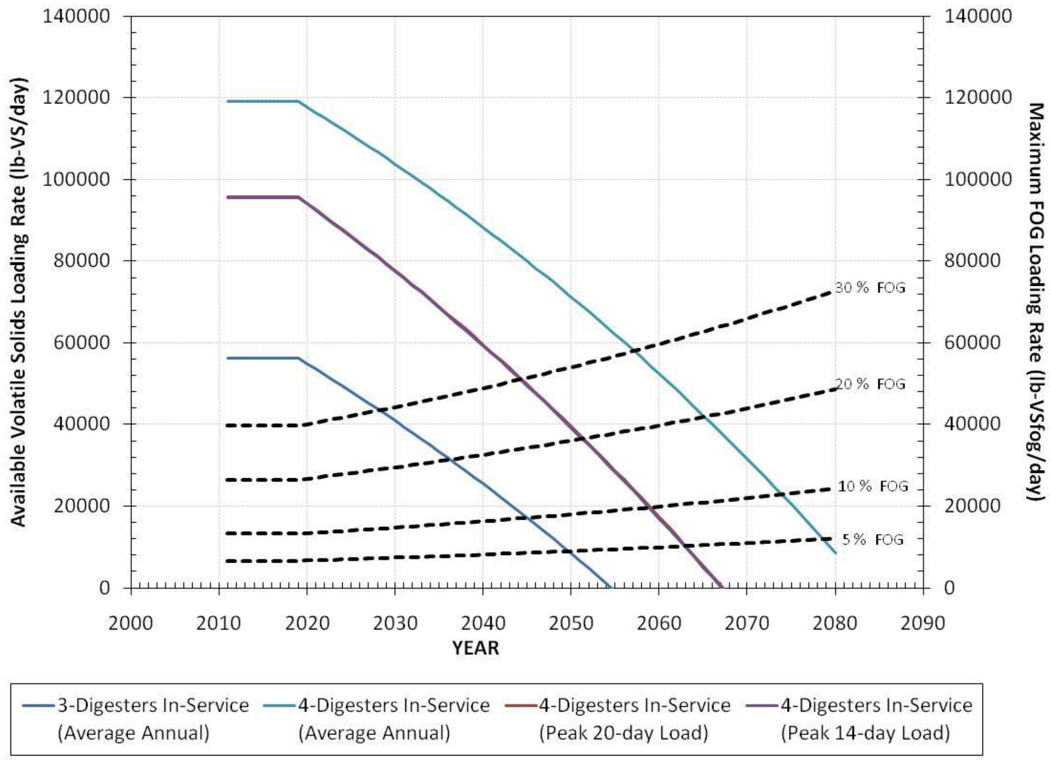


Figure ES-1. The utilization of organic loading capacity at South Plant a variable load fractions of brown grease

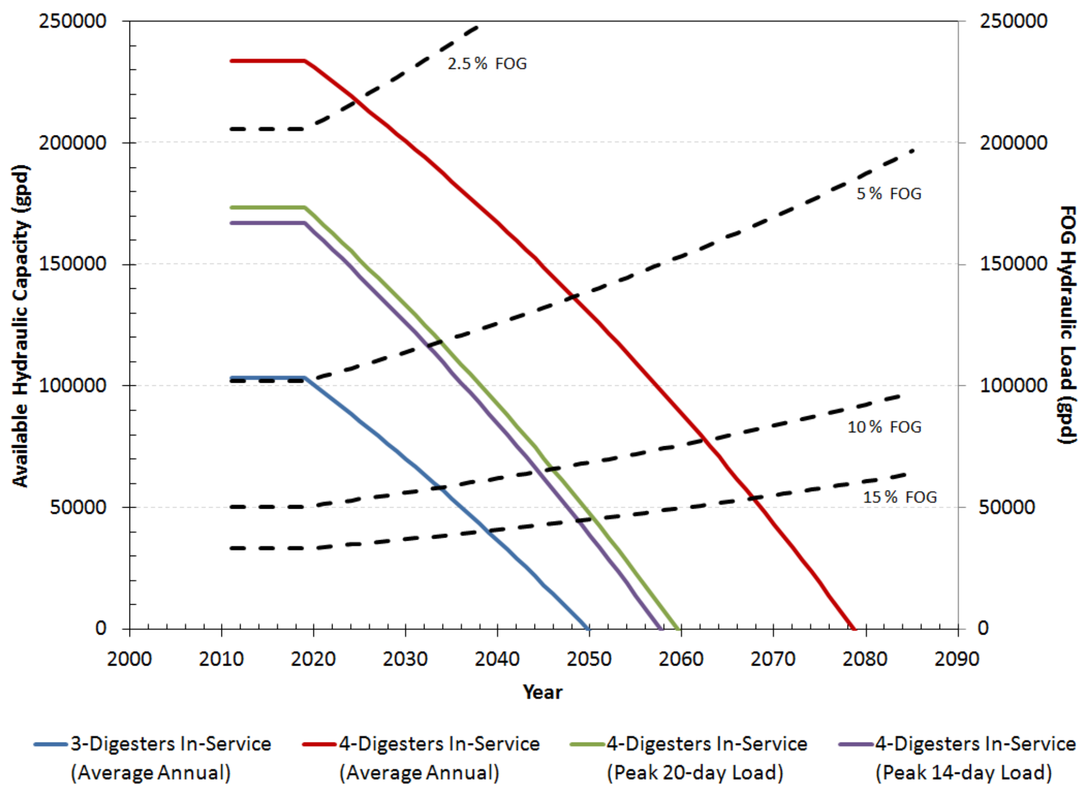


Figure ES-2. Influence of brown grease solids concentration on the hydraulic capacity of South Plant's digesters at a FOG volatile solids loads of 30 percent of average annual sludge

3. Facility Layout and Business Case Evaluation

Based on the results of the capacity analysis, a conceptual facility was developed that would allow for an initial demonstration facility sized for demonstrating co-digestion on one digester (31,000 gallons per day at 4.6% solids) as well as a full capacity facility that would accept the maximum load available (123,000 gallons per day of grease at 4.6% solids). To address the hydraulic limitations of the system a scum concentrator was included to increase grease concentrations to 20% solids. This thickening of the grease decoupled organic loading limits from the hydraulic loading limit and allowed for capacity to be extended to 2030. The disadvantage of this addition was that recycled BOD from the thickening will increase operational costs in the secondary treatment process.

A process flow diagram of the full capacity facility is presented in Figure ES-3 and a general layout of both the full facility and the demonstration facility is shown in **Error! Reference source not found.**5.

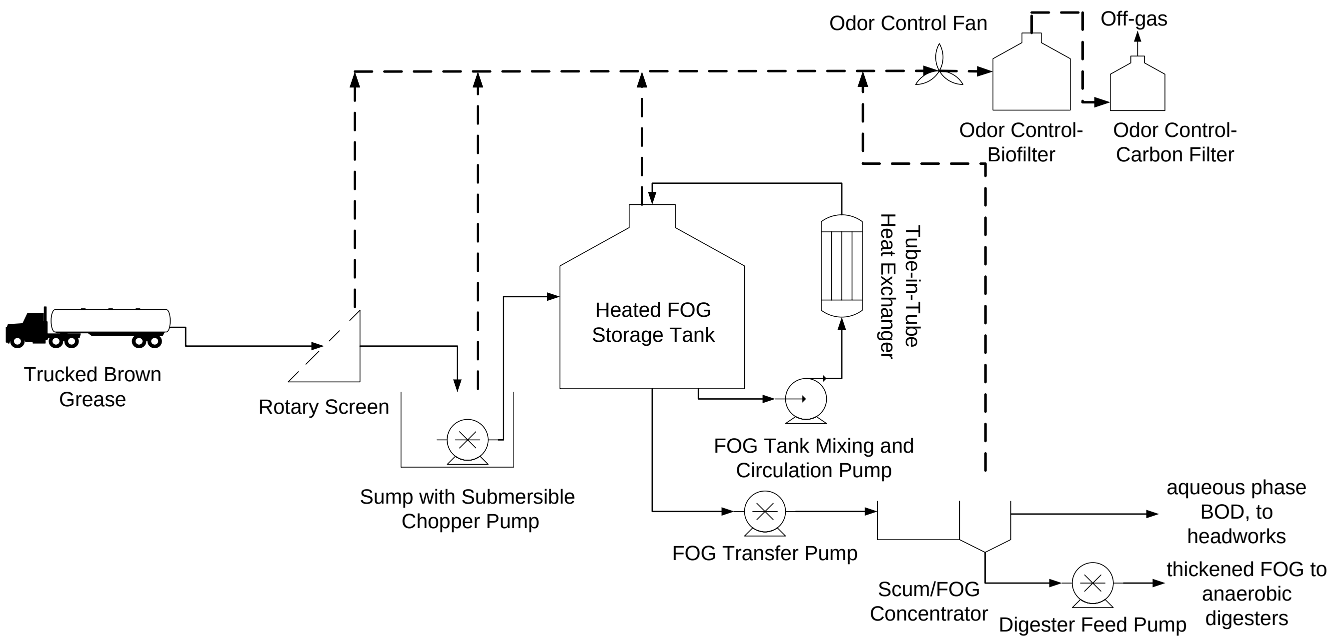


Figure ES-3. Basic process flow schematic of conceptual grease facility for South Plant

Based on this conceptual design, a BCE was conducted to assess the 20-year net present value (NPV) of both the demonstration facility and the full capacity facility. To conduct this analysis, a conceptual cost estimate was developed, operational costs were estimated, and potential revenues were included. These costs are summarized in Table ES-1. Based on a total construction cost of $4.52 million, including County allied costs, the 20-year NPV was estimated to be $15.65 million, indicating that executing the project as defined would be a benefit to the County. Should the County decide to just build the demonstration facility, construction costs were expected to be $1.24 million (including all allied costs) and a 20-year NPV return of $5.18 million was calculated. This indicates that just building the demonstration facility would be economically positive for the County over a 20-year period.

Because a number of assumptions built into these analyses have not been confirmed, a sensitivity analysis was conducted to investigate the impact of tipping fees charged to haulers and the amount of grease received daily on a volumetric basis. This analysis indicated that at a tipping fee of 5 cents per gallon, the demonstration facility would be economically viable at inflows as low as 16,000 gallons per day and the full capacity facility would be viable at flows as low as 60,000 gallons per day.

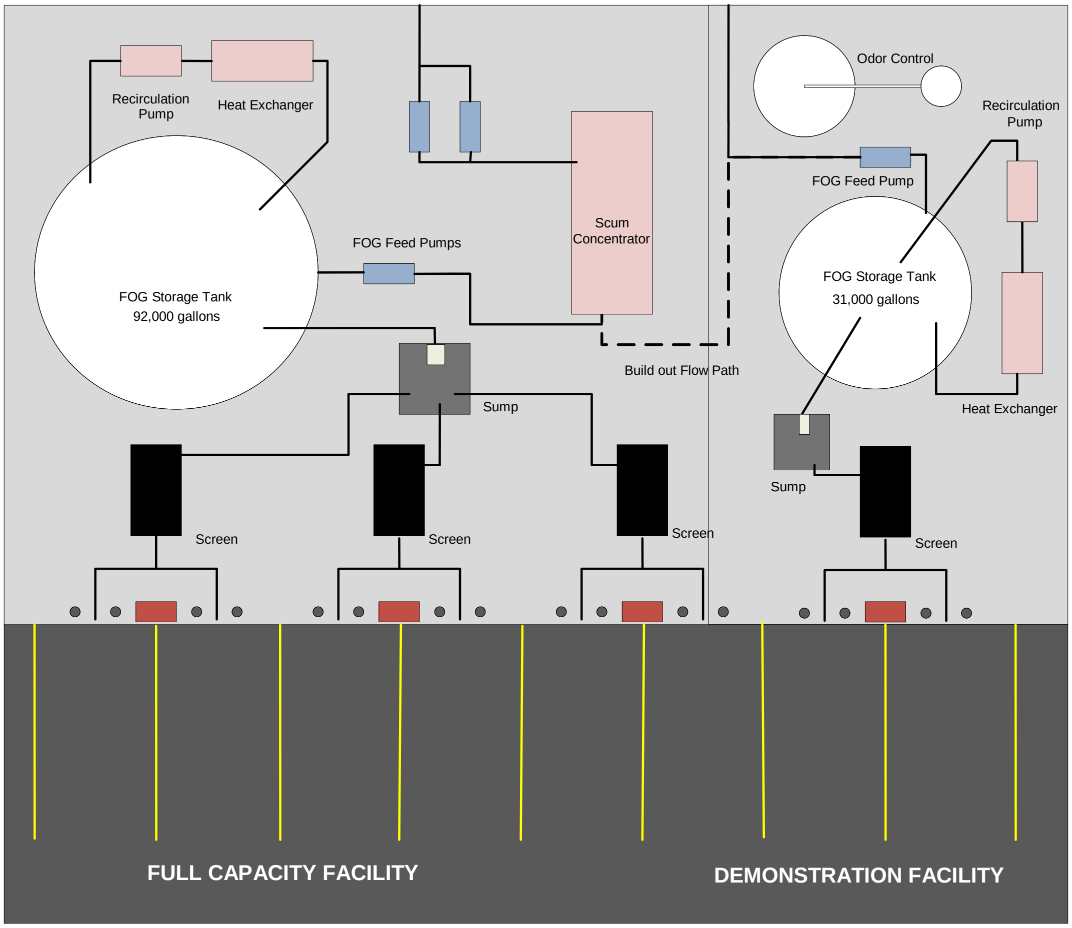


Figure ES-4. Conceptual grease receiving facility layout for South Plant

Table ES-1. 20-Year Cost and Revenue Breakdown for Grease Receiving at South Plant				
Description	Rate	Capital costs ($-million)	Total operating costs ($-million)	Total revenues ($-million)
Capital and allied costs				
Demonstration facility capital cost[a]		0.923		
Demonstration facility allied costs		0.318		
Full capacity expansion costs[a]		2.440		
Full capacity expansion allied costs		0.835		
Total capital and allied costs		4.52		
Operating costs				
Labor costs (admin and operations)	48.10 $/hr		7.96	
Power cost	0.065 $/kW-hr		2.69	
Carbon media replacement			0.037	
Biogas upgrading costs: FOG gas			5.83	
Treatment cost of recycled BOD	0.10 $/lb-BOD treated		24.28	
Biosolids disposal costs	39$/wet ton		14.94	

Dewatering polymer costs	1.05 $/lb polymer		8.10	
Total 20-year operating costs			63.84	
Revenues				
Biogas sale to PSE	$0.55914 per therm			14.86
Tipping fees	0.05 $/gal			79.14
Biosolids fertilizer surcharge	1.50 $/wet ton			0.57
Total 20-year revenues				94.57

[a] *Class 4 cost estimate per AACEI, carries a level of accuracy of -30% to +50%.*

4. Recommendations

Based on the capacity analysis and BCE, a full capacity co-digestion facility is considered viable at South Plant. Before construction of a full-capacity system can be recommended however, several assumptions, process parameters, and conditions should be validated to better execute the design of the full capacity facility and associated program. These include:

- **Market conditions:** A market analysis was not performed as part of this analysis. Therefore, it is important to ascertain if sufficient brown grease can be directed to South Plant to meet program demands. Other materials that could be used to supplement the program (e.g., food processing wastes) could also be investigated as part of this investigation.
- **Tipping fees:** Assessing the current rates being paid by grease haulers would allow the County to charge the maximum tipping fee to support revenues while still being sufficiently attractive to bring haulers to South Plant.
- **Grease characteristics:** The biochemical and physical characteristics of brown grease have been documented in the literature, but vary widely from location to location. Assessing local conditions will allow for modifications to the design (e.g., remove the need for a scum concentrator) and remove some of the uncertainty in the BCE results.
- **Synergistic effects:** There is anecdotal evidence in the literature that adding brown grease to digesters in sufficient quantities can improve process efficiency resulting in more biogas and fewer biosolids than if the materials were treated separately. Better understanding these limits could have a significant impact on the long-term benefits of operation, increasing revenues from gas while decreasing costs associated with dewatering and biosolids disposal.

To address these unknown areas, we recommend the County construct the demonstration facility as shown in the conceptual facility layout and assess the results from operating the facility before moving forward with the full-capacity facility. Operating the demonstration facility alone has a positive net present value and would provide the County with necessary information regarding the local grease market, characteristics of the grease being brought to the facility, possible synergistic effects, and any potential operational or maintenance concerns from operating the facility. Should these assumptions validate the BCE performed for the full-capacity facility, the full facility can be refined and constructed at a later date.

Attachment A: Capacity Analysis Technical Memorandum

Technical Memorandum

701 Pike Street, Suite 1200
Seattle, Washington 98101
Tel: 206-624-0100
Fax: 206-749-2200

Prepared for: King County, Washington

Project Title: Grease to Energy at South Treatment Plant

Project No.: 141326-002

Technical Memorandum 1

Subject: Digester Capacity for Acceptance of Brown Grease

Date: December 21, 2011

To: John Smyth, King County, Project Manager

Rick Butler, King County, Operations

From: Christopher Muller, Ph.D., P.E., Project Engineer

Copy to: Ian McKelvey, Brown and Caldwell, Project Manager

Prepared by: ______________________________

Christopher D. Muller Ph.D., P.E., Senior Engineer, Washington: 47853, 8/1/2013

Matthew Winkler, EIT, Engineer II

Reviewed by: ______________________________

Tracy Stigers, Vice President, Western Business Unit Wastewater Practice Leader

.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ATAD	autothermal thermophilic aerobic digestion
BOD	biochemical oxygen demand
Btu/kW-hr	British thermal unit(s) per kilowatt-hour
CHP	combined heat and power
COD	chemical oxygen demand
DAFT	dissolved air flotation thickener
°F	degree(s) Fahrenheit
FOG	fats, oils, and grease
FSE	food-service establishment
ft	foot/feet
ft^3-biogas	cubic feet of biogas
ft^3-biogas/lb-VSd	cubic feet of biogas per pound volatile solids destroyed
gpd	gallon(s) per day
HRT	hydraulic retention time
kW	kilowatt(s)
lb	pound(s)
lb-TS/day	pound(s) total solids per day
lb-VS/1,000-ft^3-day	pound(s) volatile solids per 1,000 cubic feet per day
lb-VS/day	pound(s) volatile solids per day
lb-VS_{FOG}/day	pounds FOG volatile solids per day
mg/L	milligram(s) per liter
mm scfd	million standard cubic feet per day
MW	megawatt(s)
NPDES	National Pollutant Discharge Elimination System
OLR	organic loading rate
PSE	Puget Sound Energy
psi	pound(s) per square inch
PSRP	process that significantly reduces pathogens
TKN	total Kjeldahl nitrogen
TPAD	temperature-phased anaerobic digestion
VSd	volatile solids destruction
WAS	waste activated sludge
WC	water column
WGB	waste gas burner
WWTP	wastewater treatment plant

1. Introduction

This technical memorandum reviews the evaluation of anaerobic digestion capacity at South Treatment Plant, Renton, Washington, to accept fats, oils, and grease (FOG) or brown grease from local haulers to increase biogas production and provide a disposal alternative to haulers.

A desktop evaluation of the potential excess capacity of the digestion and biogas utilization systems at South Plant was conducted. The analysis was limited in detail to evaluation of current process loading data and nameplate capacities of different energy end-use systems. It is recognized that a detailed assessment of the capacities of the ancillary processes: solids conveyance, heating, power, mixing, dewatering, thickening processes, gas conveyance, and gas safety, will need to be conducted to verify that sufficient capacity remains. Evaluation of these systems was beyond the scope of this preliminary analysis and therefore for the purposes of this analysis it was assumed that these elements have sufficient remaining capacity. It is recommended that if the County moves forward with brown grease co-digestion that all ancillary systems are verified to have sufficient capacity.

Each of the reviewed elements in the capacity assessment is summarized in the sections below.

2. Description of General Conditions

The following section describes sludge loadings to the digesters, anaerobic digestion at South Plant, and biogas utilization.

2.1 Sludge Loadings to the Digesters

The anaerobic digesters receive a combination of primary sludge and waste activated sludge (WAS) from the primary and secondary treatment systems, respectively. The primary sludge and WAS are co-thickened in the dissolved air flotation thickeners (DAFT), prior to digestion; see Figure 2-1.

Figure 2-1. Dissolved air flotation thickener at South Plant, Renton, Wash.

Plant staff also noted that they expect raw sludge production to shift due to two factors: bringing the new Brightwater Advanced Wastewater Treatment Plant (WWTP) online in July 2013 and increasing septage loading to the plant from haulers. When Brightwater commences full operation, flows that were traditionally swapped between South Plant and West Point Treatment Plant during the year will be directed to Brightwater full-time. It is anticipated that Brightwater operation will decrease the solids production at South Plant during the winter months when historically the flows and loads are the highest. As Brightwater is not online yet, no historical data are available to estimate its impact on South Plant operations; therefore, King County and Brown and Caldwell will develop an estimate for the impact of Brightwater on solids loading to the plant.

The operations staff reported that septage loadings to the plant have increased over the last few years. Staff estimate that in the last 3 years septage loads have increased from 14 million gallons per year to approximately 28 million gallons per year. This equates to about 4 percent of the plant's solids production. The septage solids are not nearly as volatile as primary sludge or WAS, having a volatile content of only 72–79 percent. Further septage typically is collected from a home on an annual basis, allowing significant time for degradable organics to be consumed and therefore is likely not to have the same biogas production potential, as undigested sludge or brown grease. Septage is received at the south side of the plant from Longacres Road, where the trucks come in to be weighed prior to disposal. Increased septage receiving will consume digester capacity and will need to be assessed in the projection of solids system capacity.

2.2 Anaerobic Digestion at South Plant

Currently South Plant processes raw sludge through its mesophilic anaerobic digesters to produce biogas and Class B biosolids. A basic process flow diagram for the South Plant solids stabilization process is shown in Figure 2-2.

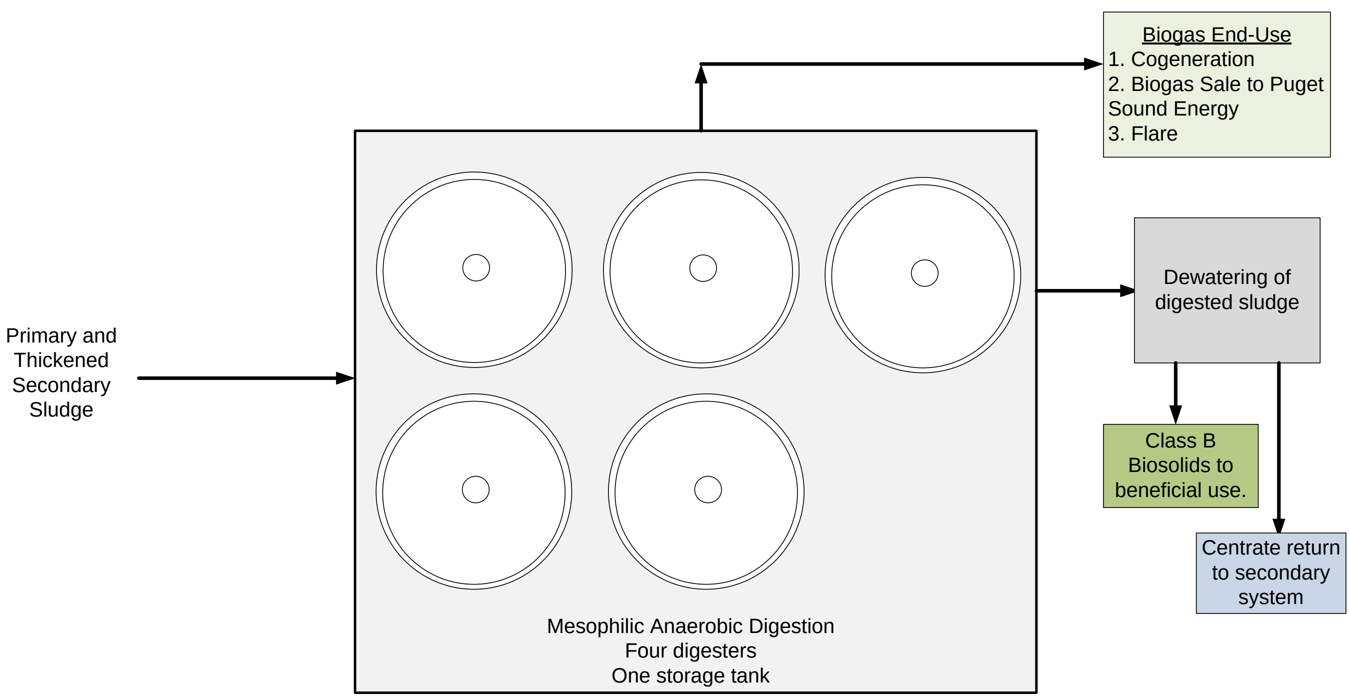


Figure 2-2. Basic process flow diagram for the solids stabilization process at South Plant

The digestion system consists of four active digesters and one storage tank, all of equal size. The active digesters have floating covers and the storage tank has a fixed cover; see Figure 2-3. The digesters are operated at mesophilic conditions, 95–99 degrees Fahrenheit (35–37.2 degrees Celsius). A recent dye tracer study conducted by the County indicated that with its combination of gas mixing and pump mixing, the system achieves approximately 95 percent active volume. Table 2-1 summarizes the basic characteristics of the digestion system operated at South Plant, as reported by King County.


(a)


(b)

Figure 2-3. Floating-cover digesters (a) and fixed-cover digested sludge storage tank (b) at South Plant

Table 2-1. Basic Characteristics of South Plant Digestion Process

Parameter	Value	Notes/comments
Anaerobic digesters	Data	Data
Number of tanks	4	
Tank inner diameter (ft)	100	
Design volume (million gallons)	2.75	
Percent active volume (percent)	95	King County (2011)
Active volume (million gallons)	2.61	Design volume x percent active volume
Mixing type	Pump mix/gas mix	Both types in each tank
Digester cover type	Floating	
Storage tank cover type	Fixed	
Pressure relief valve setting (inches of water column)	14	King County (2011)
Biosolids product	Class B	
Operating temperature (°F)	95–99	
Digested sludge concentration (percent dry solids)	2.9–3.3	
pH	7.4–7.6	
Volatile acids	N/A	Not measured due to test reliability
Volatile solids destruction (percent)	59–62	

While the digesters operate very well at South Plant, with near complete mix and high volatile solids destruction (VSd), the plant does experience some operational issues related to struvite (magnesium ammonium phosphate). Operations reports that struvite is precipitating in the tube-in-tube heat exchangers and are now on a cleaning schedule of one heat exchanger per year. Plant staff report that after 2 to 3 years of operation the heat exchangers typically show about 2 inches of scale development.

County operations staff noted that the process exhibits undesirable solids characteristics (odors) when the hydraulic retention time (HRT) is below 18 days and therefore try to maintain HRTs longer than 18 days. Currently the system has an average HRT of 27–30 days with three of the digesters in service.

The biosolids generated from the digestion process are dewatered using Andritz centrifuges, and sent to various Class B biosolids land application sites.

2.3 Biogas Utilization

A product of anaerobic digestion is biogas, which is comprised of methane, carbon dioxide, nitrogen, and various trace species (hydrogen sulfide, methyl-mercaptan, etc.). King County beneficially uses its biogas as a fuel for digester heating, power generation, and sale to the natural gas utility. The biogas generated from the digesters is processed as depicted in Figure 2-4.

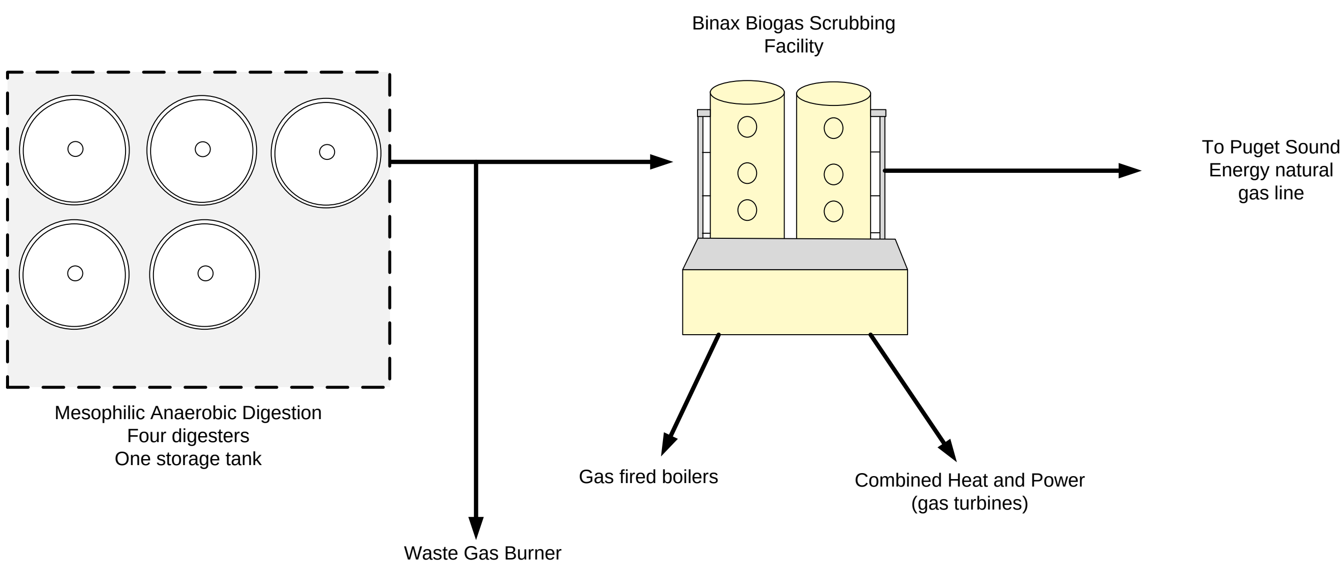


Figure 2-4. Basic biogas process flow diagram for South Plant

South Plant currently processes all of the raw biogas through its biogas cleanup process prior to introduction to the boilers, natural gas lines, and/or gas turbines. This approach is used both to achieve the biogas quality required by Puget Sound Energy (PSE) and to reduce wear and maintenance on the boilers and turbines. In the event that either of the turbines are offline, heating demands are met, or PSE will not accept gas, additional biogas is sent to the waste gas burners (WGBs). It should also be noted that a fuel cell is located on the South Plant property; however, it is no longer in service and will at some point be removed by the vendor. Therefore, it is not considered any further in this analysis. The following subsections discuss the different biogas end uses available at South Plant.

2.3.1 Binax Biogas Scrubbing to the Natural Gas Grid

The Binax system, shown in Figure 2-5, removes impurities and carbon dioxide from biogas to generate biomethane of sufficient quality to be introduced to the PSE natural gas grid. Currently King County receives the unit price for gas from PSE for the gas introduced to the grid.

(a) (b)

Figure 2-5. Binax biogas scrubbing facility at South Plant:
(a) water scrubbing towers and (b) mercaptan addition facility

This end use is not always available to or used by the County. When utility pipeline pressures reach 250 pounds per square inch (psi), the County can no longer introduce biomethane into the grid. Also during high electrical demand periods, during which electrical power rates are set, South Plant diverts biogas to the gas turbines to produce power and reduce peak demand charges.

Plant staff have noted that the system is currently limited to producing 11,000 to 12,000 therms per day. The primary constraint on the system is the ability to provide sufficient water. County staff indicated that the compressors capacity also limits the capability of the scrubbing process. Table 2-2 summarizes the compressors capacities.

Table 2-2. Summary of Binax System Compressor Capacities

Unit description	Value	Units
Compressor 1	0.5	MSCFD
Compressor 2	0.5	MSCFD
Compressor 3	1.2	MSCFD

2.3.2 Gas-Fired Turbines

South Plant has three gas-fired turbines (see Figure 2-6), which can be used to generate electrical power and heat, which can then be recovered for process heating. The gas turbines are currently operated only during peak energy demand periods to shave the peak demand (peak ratchet) load and to reduce demand charges from PSE. The turbines are in standby mode because the biomethane has a higher commodity value than the power generated, typically.

Figure 2-6. Gas turbines CHP system at South Plant, Renton, Wash.

2.3.3 Waste Gas Burners

South Plant has three waste gas burners (WGBs) at the plant, as shown in Figure 2-7: two duty and one standby. The County initially estimated that the flares are at about 80 percent of capacity at current loadings. According to the County the flares are set to open at 7 inches of water column (WC), with the pilot light at 8 inches WC. When the North Creek and York flows are directed to South Plant (flows that will ultimately go to Brightwater), about 10 percent of the biogas is flared as it can not all be processed by the Binax gas scrubbing unit.

Figure 2-7. Waste gas burners at South Plant

3. Co-Digestion of Brown Grease

The following section describes the characterization and methods to quantify and characterize brown grease, and potential process implications of adding it to digesters.

3.1 Characterization of Brown Grease

The quality of brown grease (e.g., nutrient content, volatile solids [VS] content, degradability) depend on several parameters, all of which are important to King County as each has an impact on the process and the net energy available for sale or offset. The volume of grease collected by the haulers and brought to South Plant will be a function of the concentration of materials collected. A good hauler will minimize the water collected from a grease interceptor or trap, increasing the concentration of desirable product and reducing the concentration of undesirable product (water). However, some city ordinances require that grease interceptors be pumped clean, eliminating any chance to not collect water. Other factors influencing grease acceptance will include attractiveness of the site and active management to maintain and build a customer base. Table 3-1 summarizes literature-reported values for different grease products.

Table 3-1. Brown Grease Characteristics from Industry Data

Description	Total solids (percent)	Volatile Solids (percent)	Volatile Fraction (percent)	Chemical oxygen demand (mg/L)	Number of samples	Reference
Dewatered FOG	21.2	n/a	65.7	372,000	1	Brown and Caldwell (2010)
Pump truck contents	4.4	n/a	94	81,831	65	Brown and Caldwell (2009)
Pump truck contents	<1–>15	n/a	90–97	n/a	n/a	Schafer et al. (2008)
Grease traps	5–10	n/a	n/a	n/a	n/a	Wiltsee (1998)
Partial dewatered FOG (gravity drainage +polymer)	32.5	n/a	96.2	n/a	n/a	Kabouris et al. (2008)
Grease traps	57	56.9	99.7	n/a	n/a	Zengkai (2011)
Brown grease at grease receiving station	3.2	3.0	93.9	n/a	n/a	Wan et al. (2011)
Restaurant grease	97.2	97.2		n/a	n/a	Parry et al. (2009)
Thickened grease trap waste	17.3	17	98.3	n/a	n/a	Davidson et al. (2008)
Screened grease wastewater	11.5	10.8	93.5	n/a	n/a	Bailey et al. (2007)
Composite brown grease sample	4.4	3.5	90.6	n/a	n/a	Suto et al. (2006)

n/a = values not reported

volatile fraction = Volatile Solids/Total Solids, percent basis

Typically for utilities practicing co-digestion, the total concentration of solids, volatile solids, or chemical oxygen demand (COD) are sufficient to describe the benefits of grease addition to an anaerobic digester. Depending on available capacity and King County preferences, the pre-processing of brown grease can take several forms, which may or may not impact the energy content of the hauled grease. Suto et al. (2006) evaluated the stratification of brown grease, noting three distinct layers: floatables, aqueous, and solids phase, as shown in Figure 3-1.

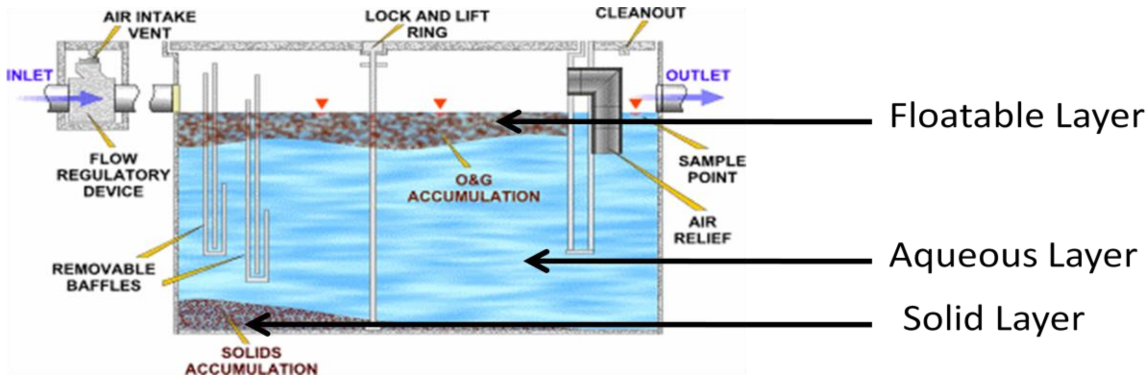


Figure 3-1. Identified materials layers in brown grease samples

If gravity thickening of brown grease (ex. scum concentrator) occurs prior to digestion, a significant fraction of COD remaining in the aqueous layer will be rejected and sent back to the primary and secondary treatment systems for treatment. The rejected flow ultimately increases soluble biochemical oxygen demand (BOD) returned to the secondary system for aerobic degradation. This added return load not only increases aeration demand but also consumes a fraction of the plant's secondary treatment capacity.

The Suto et al. (2006) report identified the different separable layers in a brown grease sample and attempted to quantify the distribution of COD within the layers, using what was described as a stratification test. The results of the analysis are presented in Table 3-2, showing the minimum, maximum, and average percent volume of the sample represented by each layer classification.

Table 3-2. Percent of Brown Grease Sample Volume Occupied by Different Classes of Materials

Layer	Minimum volume	Maximum volume	Average volume
Floatable layer	0	85	19
Aqueous layer	0	85	37
Solid layer	0	100	50

Source: Suto et al. (2006).

Using the data in Table 3-2 and those reported in the original work an estimated percent of total COD load for each layer was made, as shown in Figure 3-2. The solids layer and the floatable layers represent approximately 76 percent of the total COD in a given sample, which means that approximately 24 percent of the accepted COD or more could be returned to the secondary treatment system, if solid/liquid separation was practiced.

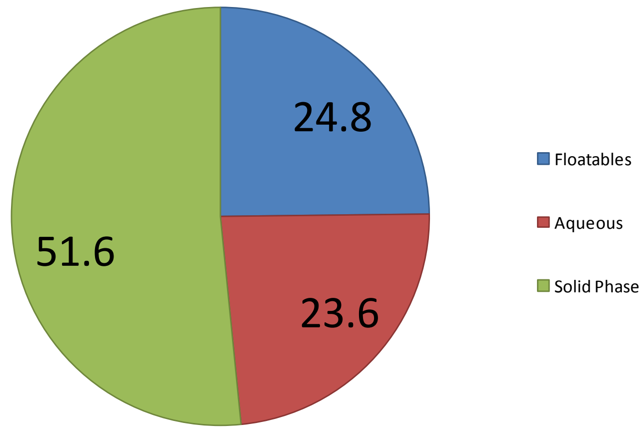


Figure 3-2. Average percent of total COD load in different phases of interceptor trap materials

Source data: Suto et al. (2008)

Depending on hauler practices and facility design, a significant fluctuation could develop in the net COD sent to the anaerobic digesters. In follow on efforts, the County should evaluate the net flow of COD to different unit processes based on different receiving station designs. The net impact on energy relative to operability and operating cost should be evaluated.

For this preliminary analysis it is assumed that the FOG will not be thickened and the entire contents will be sent to the digester.

3.2 Methods for Quantification of Brown Grease

This initial analysis does not include an estimate of the potential amount of brown grease in the King County service area available for co-digestion. Estimation of the quantity of grease in a particular service area will be important in defining the fiscal and environmental benefits of the program and the size of equipment and ultimately impact process capacity and size of the receiving facility.

Population-based approaches can be used, such as the methodology developed by Wiltsee (1998), or direct surveys of haulers and grease generators in the region can be conducted. Each approach is discussed below.

Wiltsee (1998) Population-Based Estimate. George Wiltsee developed estimates of the annual per capital production of grease for different localities as well as the United States in general based on a survey he conducted for the National Renewable Energy Laboratories. The estimate is based on interviews with local haulers, a number of grease producers, and measurements of grease in the influent of WWTPs in different cities. Based on this analysis the estimated national average is 8.87 pounds (lb) of yellow grease and 13.37 lb of brown grease per person per year.

Wiltsee (1998) also reported grease production for Olympia, Washington, a regionally relevant comparison. On average, Olympia generates 6.7 lb of yellow grease and 7.44 lb of brown grease per person per year, slightly lower than the national average. Estimating grease production/availability based on this method can overestimate or underestimate depending on local conditions. Further, the values reported by Wiltsee

(1998) include grease that is not normally recovered by haulers, such as materials entering the sewer from residences; therefore expected grease from haulers must be adjusted to reflect such differences. Table 3-3 summarizes the estimated grease production for King County based on different rates reported by Wiltsee (1998).

Variability in the per capita production at the metropolitan areas shown in Table 3-3 indicates that grease production is not directly tied to population alone, but is more region-specific. The data show that total grease production could range from approximately 13 million to 33 million pounds per year using the Wiltsee (1998) estimate for different regions (Table 3-3). Further supporting the regional specificity of grease production rates is an observation made by Garza (2004) that the cuisine type impacts the strength of wastewater from different food-service establishments (FSEs), a common source of grease in sewerage systems.

Table 3-3. Estimated Total Grease Based on Wiltsee (1998) Population Based Estimate

	Grease production rate[b]	2010 King County population[a]	Estimated total grease production
Parameter	lb-grease/person-yr	persons	lb-grease/year
U.S. national average			
Brown grease	13.37	1,931,249	25,820,799
Olympia, Wash. (population: 161,238): regionally relevant			
Brown grease	6.67	1,931,249	12,881,431
Boston, Mass. (population: 1,950,855): similar population			
Brown grease	17.22	1,931,249	33,256,108
Denver, Colo. (population: 1,848,319): similar population			
Brown grease	8.6	1,931,249	16,608,741

a. King County population based on U.S. census data, U.S. Census Bureau (2011).

b. All grease production rates and other city populations are from Wiltsee (1998).

Given the variability in the population based estimates and the lack of clarity in the different sources of brown grease, care should be used in applying them. Brown and Caldwell would not recommend using these values to design facilities and project revenues. These values are useful in generating order of magnitude estimates, but direct surveys would be preferred.

Hauler Interview Estimate. Grease haulers can be an excellent source of information for estimating the available brown and yellow grease in a specific market. Depending on the market, some haulers are willing to share information and/or participate in testing.

Grease haulers collect grease and other waste liquids from a variety of locations, though primarily from FSEs. Some haulers collect just grease while others will co-collect grease and septage, a mixture that would be expected to reduce the energy benefit from grease receiving. However, from prior contact with haulers, a willingness to collect separate loads has been noted. Other considerations when working with haulers are as follows:

- **Current disposal location**: Identifying the current disposal/use for brown grease will help determine both the environmental benefit and the potential for reduced overhead costs for hauling companies. Reduced hauling costs for a grease trap servicer can improve its margins, making a close site more cost-effective and increasing the potential for participation.

- **Current tipping fees**: Typically haulers are charged a tipping fee to dispose of brown grease, whether at a landfill or other facility. When presented with multiple disposal options, tipping fees combined with haul distance will influence where the hauler disposes of the materials.
- **Quantity of material**: Estimating the quantity of material is critical to understand the number of trucks that will be entering a receiving facility and the size of the facility needed. If the facility is too small, haulers will have to wait for dumping, which could impact the program's attractiveness and create unnecessary traffic issues at the plant.
- **Handling practices**: Some haulers have reported decanting trucks to thicken grease prior to disposal. This is an attractive practice when haulers are charged on a volumetric basis (dollar per gallon).
- **Load composition**: Understanding the composition of the typical load collected by a hauler will be important as the County is interested in collecting brown grease only. The addition of septage could reduce the fuel value of the material to be directed to the digesters. Haulers who co-collect should be encouraged not to commingle septage and brown grease.
- **Load characterization**: Sampling of haulers' contents during the planning stage can provide useful information as to the quantity of grease and water in each load. Haulers should be encouraged to participate in a sampling program run by the County during the analysis period.

Food-Service Establishment (FSE) Survey. FSEs are among the largest sources of FOG in a service area. FSEs, including restaurants and commercial food processors, produce FOG as a byproduct of food production. Some municipalities have grease control programs to limit the amount of grease discharged to their sewers. These programs typically involve the installation and maintenance of grease control devices, such as grease interceptors, which require periodic servicing to help prevent FOG from entering the sewer.

Contacting local FSEs can provide an estimate of the number of grease control devices, their size, and who is servicing them. A survey of FSEs could provide needed information regarding current practices and degree of best management practice implementation. While the results may be promising, past experience with surveying businesses found that getting responses can require significant effort and is not always fruitful.

Department of Health and FSE Licensing Department Survey. A survey of the records held by the Department of Health and/or business licensing can be beneficial. These agencies could have records showing if grease control devices are in place and/or can provide a list of businesses which should have a grease control device. Recently, Brown and Caldwell has worked with the City of Bellingham and Whatcom County Department of Health to generate a survey using this type of data.

3.3 Process Implications of Brown Grease Addition

The addition of brown grease to digesters is becoming more common as utilities try to reduce energy purchases, reduce carbon footprint, and put their exiting infrastructure to work. However, the addition of brown grease to digesters is not as simple as adding more sludge to a digester, as it has physical characteristics and biological limits that must be accounted for.

Table 3-4 provides some degradability characteristics as well as gas yields reported in literature. The values shown in Table 3-4 demonstrate the higher degradability of lipid-based substrates than sludges, assuming that COD removal is approximately equivalent to VSd.

Table 3-4. Literature Reported Process Data for FOG Degradation

Reference	FOG VSR	FOG CODr	Biogas yield	Methane yield	Biogas methane content	Notes/comments
	Percent	Percent	m^3-biogas/ kg-VSd	m^3-CH4/kg-VSd	percent	
Li et al. (2002)	NR	NR	1.425	NR	69.5	Theoretical maximum for lipids

Kabouris (2008)	NR	90.9–95.6 [a]	NR	0.909–1.146	NR	Batch test, Bench, Phase 1
Kabouris (2008)	NR	77.7–84.7 [a]	NR	1.111–1.358	NR	Batch test, Bench, Phase 2

a. Calculated based on methane yield balance.

NR = not reported.

A review of the literature indicates the potential for a synergistic effect on the digestion process from the addition of sufficient quantities of FOG to a digester. This synergistic effect, as explained by Schafer et al. (2008), is a phenomenon in which co-digestion of FOG with sewage sludge results in better performance (greater volatile solids destruction) than if the substrates were digested independently. Figure 3-3 shows graphically the theoretical impact of synergistic effects on biogas production.

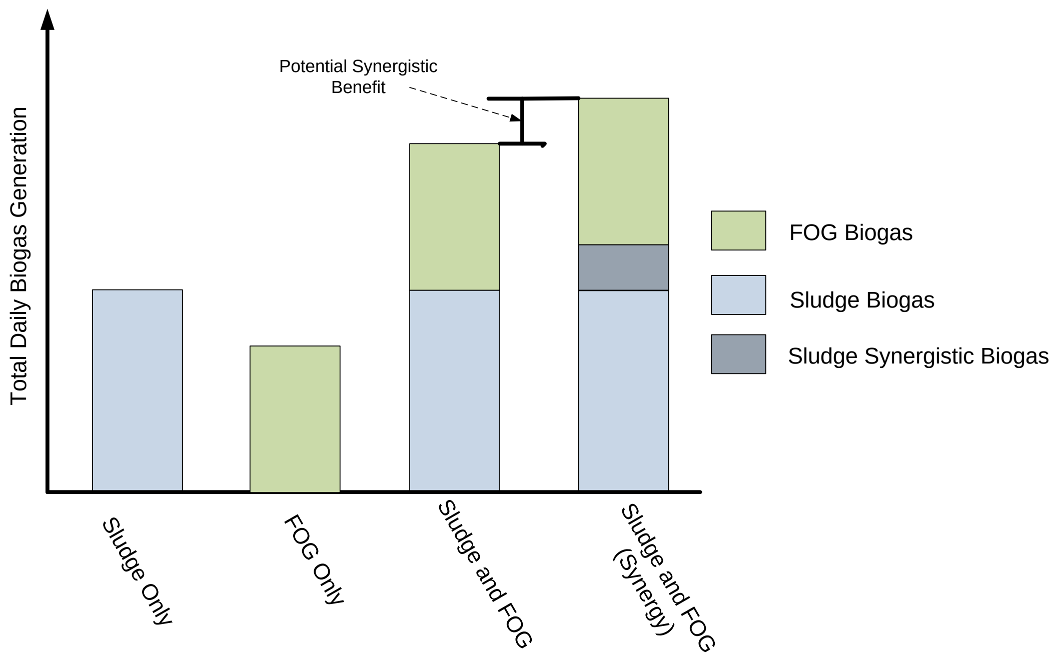


Figure 3-3. Theoretical benefit of synergistic effects on biogas production from the co-digestion of grease with sewage sludge

The basis for the improvement in overall digestion as a result of brown grease addition is not currently defined in the literature and several factors could contribute to this phenomenon. These factors could include the following:

- **Artifact of measurement**: The accuracy of VSd measurements depends upon several factors: quality of sampling technique, quality of measurement technique, digester mixing conditions, and calculation method used. Muller et al. (2010) noted that when digesters are poorly mixed, the mass balance approach overestimates VSd and the Van Kleeck approach underestimates VSd.
- **C:N:P ratios:** Carbon, nitrogen, and phosphorus are all needed in sufficient quantities to support microbial growth. Typically in anaerobic digesters, nitrogen (in the form of ammonium) and phosphorus are in abundant supply, as they are discharged in the digester effluent. It has been hypothesized that anaerobic digesters are carbon-limited systems, in that there are more nutrients than carbon to utilize for cellular growth. Gerardi (2003) states that nutrient demands increase with increasing digester loading, and that there is an optimal carbon-to-nitrogen ratio for biogas production. Figure 3-4 provides a summary of grab samples taken as part of a co-digestion feasibility study. Figure 3-4 shows that while many materials have higher COD concentrations than the sludge (autothermal thermophilic aerobic digestion [ATAD] sludge) it

is often accompanied by high or equivalent nitrogen levels, except for those that have high fat contents such as primary scum, brown grease, and food processing DAFT floats.

- **Micronutrient limits**: Some authors have reported that anaerobic digesters can be limited by a lack of micronutrients. Micronutrients reported to have a stimulatory effect on digesters include iron, nickel, cobalt, zinc, copper, manganese, molybdenum, selenium, tungsten, boron (Speece, 2008), and sulfur (Gerardi, 2003). Kemp et al. (2008) investigated the impact of iron-only addition on the performance of temperature-phased anaerobic digestion (TPAD) and found reduced effluent volatile acids concentrations, an indicator of more efficient digestion. Speece (2008) reported that micronutrients have to be both present and bioavailable.

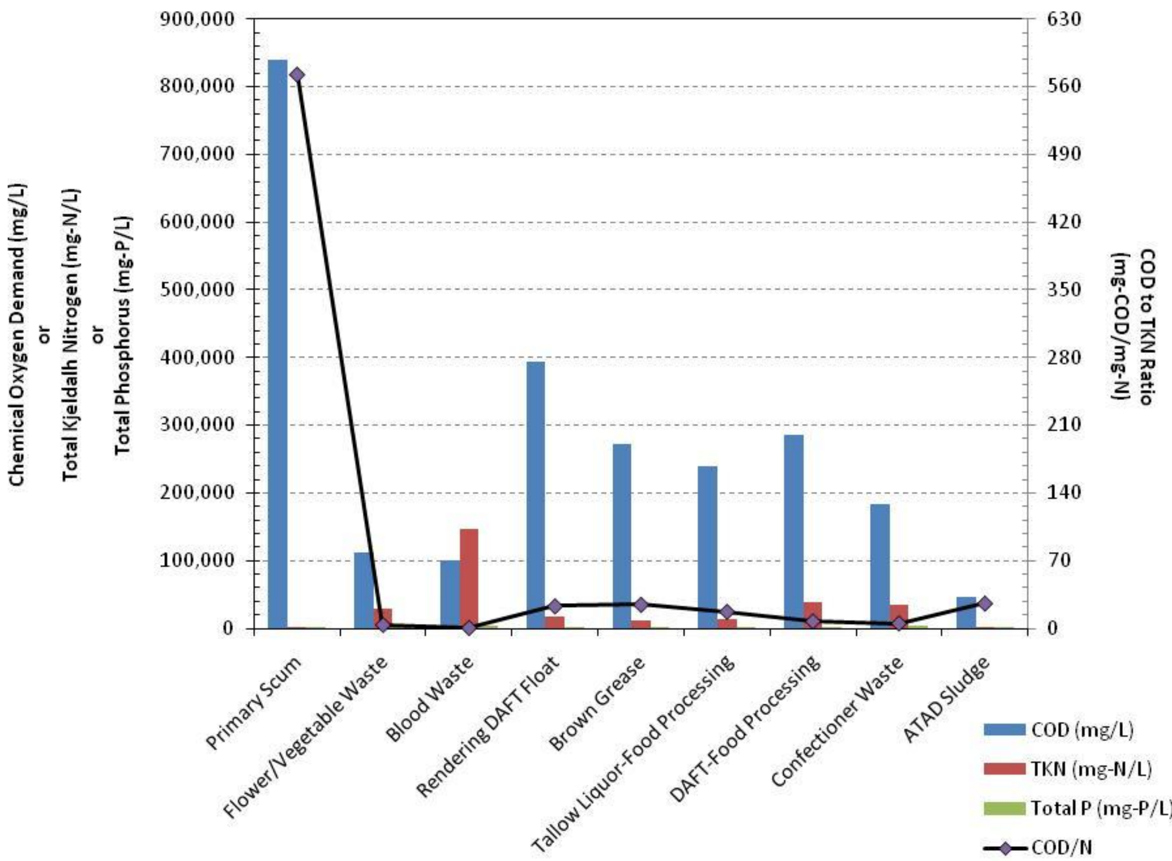
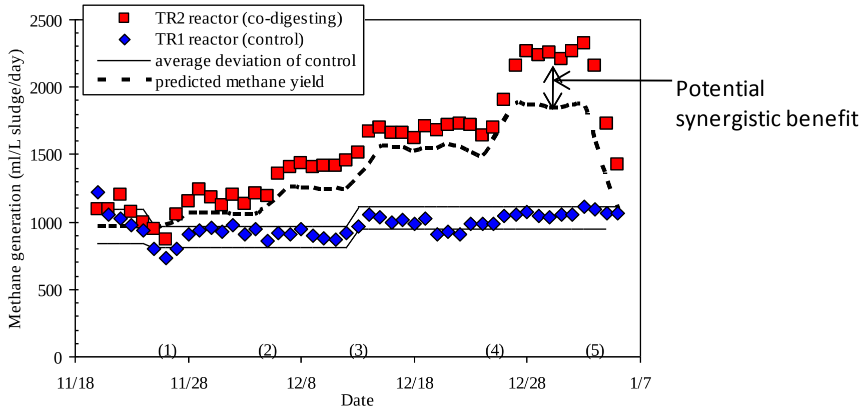


Figure 3-4. Summary of COD, total Kjeldahl nitrogen (TKN), and total-P content of various grab samples of co-digestion substrates

While much of the current evidence is either anecdotal, observations from plants, or personal communications among industry professionals, research is beginning to be conducted on co-digestion. Data from Ferguson and Gough (2009) evaluating increasing FOG loads to a thermophilic digester demonstrated a divergence in the predicted biogas production with the observed biogas production when the FOG load reached about 25 percent on a COD basis (Figure 3-5)—an observation that was not consistently made with other co-digestion substrates tested in the study. While this single data set does not provide proof of concept, it does suggest that additional research and testing is warranted.



	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Change in Methane Production (%)	34	55	75	109	n/a
Total COD Load as FOG (%)	6.9	13	17	25	0

Figure 3-5. Potential synergistic effect of FOG addition to bench-scale thermophilic digesters

Based on the current understanding of synergistic benefits of co-digestion, it cannot be ruled out. However, accounting for the synergistic impact on digestion should be corroborated with pilot testing in order to assess the impact on other processes and equipment.

4. Capacity Assessment of Facilities at South Plant

This section provides an analysis of the capacity of South Plant to accept brown grease now and in the future. The assessment of capacity is based on the capability of the digestion process to handle the increase in organic and hydraulic load and principal pieces of equipment to handle the additional biogas. An assessment of the capacity of ancillary equipment capacity was not conducted as part of this analysis. The available capacities reported in this section assume that ancillary equipment is not limiting. It is recommended that King County evaluate the capacity of ancillary equipment prior to the implementation of a brown grease acceptance program.

4.1 Solids Projections and Peaking Factors

An assessment of co-digestion potential at South Plant must not only consider current capacity but future capacity as well. In the analysis conducted below solids production, hydraulic loading and subsequent biogas and biosolids production are based on the observed peaking factor between current average annual conditions and maximum events. The flow and load conditions evaluated in this analysis were as follows:

- *Average Annual*: the running average of the total data set was evaluated on 365 day running average with the maximum value setting the base year (2011) average annual condition
- *Maximum 30 Day*: the running average of the total data set was evaluated on 30 day running average with the maximum value setting the base year (2011) maximum 30 day value.
- *Maximum 20 Day*: the running average of the total data set was evaluated on 20 day running average with the maximum value setting the base year (2011) maximum 20 day value.
- *Maximum 14 Day*: the running average of the total data set was evaluated on 14 day running average with the maximum value setting the base year (2011) maximum 14 day value.

- *Maximum 7 Day*: the running average of the total data set was evaluated on 7 day running average with the maximum value setting the base year (2011) maximum 7 day value.
- *Maximum Day*: the maximum day was based on the maximum day loading across the data set.

The primary objective of this analysis is to determine if there is sufficient digester capacity and biogas use capacity to support a brown grease co-digestion program. Volatile solids and hydraulic loading are the primary parameters effecting digester capacity. Therefore peaking factors were developed based on these parameters. Because Brightwater will soon be in operation and take the flows from North Creek and York, reducing the flows to South Plant, peaking factors were developed to reflect this. The methodology used to account for Brightwater are described later in this document. In cases where total solids are reported, it was assumed that the volatile fraction of the raw sludge was constant at 84.5 percent and 92 percent for raw sludge and brown grease, respectively. Table 4-1 summarizes the peaking factors used in this report based on County data from 2007 through 2011.

Table 4-1. Peaking factors for conversion from average annual to maximum conditions for solids and flow projections

Condition	Volatile Solids Loading	Hydraulic Loading
Average Annual	1	1
Maximum 30 Day	1.144	1.147
Maximum 20 Day	1.176	1.210
Maximum 14 Day	1.178	1.232
Maximum 7 Day	1.214	1.287
Maximum Day	1.348	1.359

For process reasons discussed in later sections of this report, the addition of brown grease will be assessed on a percentage of the average annual volatile solids load. However, it should be noted that currently there is no information available on the potential peaking of brown grease to the plant (i.e. fluctuations in daily loads or seasonal loads). The extent of peaking can be influenced by several factors including, how many haulers the County allows per day, how many haulers can use the facility, the quality of materials received, on site storage of materials, and/or alternative disposal options available to program haulers. It is recommended that the County structure their program and process to control peaking of brown grease and conduct an analysis to determine the potential for peaking from this market sector. The implications of peaking can be significant to the process, including overloading, exceeding equipment capacities to convey solids, exceeding capacities of biogas end-use technologies, biogas conveyance, and safety equipment. Further all excess gas beyond usage capacity, even in the short term, is a lost benefit in energy revenues.

The assessment of future sludge production and flows was based on information provided by King County.

- The County estimates that solids production at South Plant will be flat until approximately 2019, 0 percent increase in sludge from year to year
- For years after 2019 the County is anticipating an annual increase in raw sludge production at 1 percent per year.
- It is assumed that both sludge loads and flows will increase at these same rates.
- It is assumed that significant process changes will not occur over the course of the projections.

- Further if it is assumed that the wastewater treatment processes will not change in a manner that would change sludge yields and characteristics in a significant way.

If changes do occur it is recommended that the projections, capacity estimates, and conclusions drawn from this analysis be revisited.

4.2 Assessment of Digestion Process Capacity

The digestion process at South Plant consists of four digesters operated in parallel with a fifth digester functioning as a heated storage tank. Figure 4-1 provides a process flow schematic of this operating regime. For this analysis it was assumed that the digestion process will continue to operate in parallel, though the County is investigating series digestion as well. Capacity limits were calculated for series digestion for informational purposes.

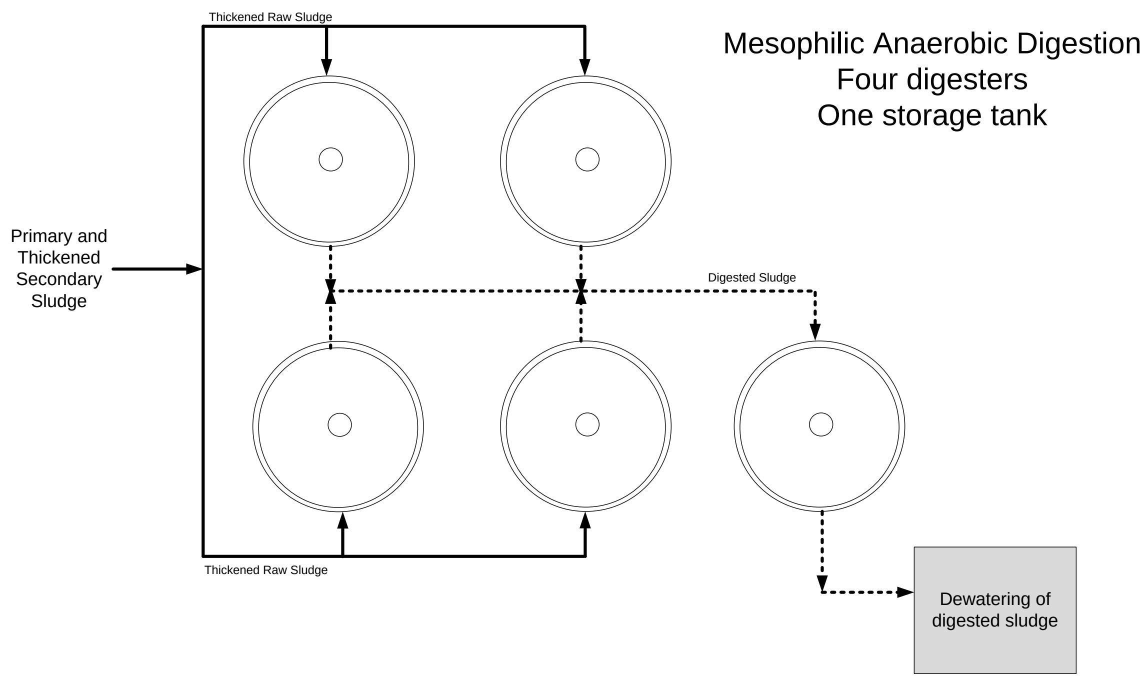


Figure 4-1. Process flow diagram of South Plant digesters

The anaerobic digestion process at South Plant was evaluated for its potential to accept brown grease. Current organic and hydraulic loadings were based on data provided by King County for the past 4 years (2007 through 2011). The County noted in the project kickoff meeting that it would like to operate its digesters at a minimum retention time of 20 days each, and not allow the process to drop to the minimum 15 days allowed by the U.S. Environmental Protection Agency (EPA). The limitation on the hydraulic retention time is due to a deterioration in the biosolids stability and an increase in odors at lower retention times. In this analysis it was assumed that a 20 day retention time will be maintained under all operating conditions, including digester out of service conditions. The maximum allowable organic loading rate (OLR) was set at 180 pounds volatile solids per 1,000 cubic feet per day (lb-VS/1,000-ft^3-day), for a mesophilic system under a maximum 14-day loading condition, to ensure process stability.

Table 4-2 provides a summary of the current flows and loads to the anaerobic digesters at South Plant. The current flows and loads will be influenced by a couple of factors in the near future: the commissioning of the

Brightwater Advanced WWTP and the continued acceptance of septage at South Plant. The influence of Brightwater will not be directly measured for several years; therefore, an estimate of the impact was made based on King County operating experience and direction. The County noted that solids production was approximately proportional to the flow to South Plant, so when the York and North Creek lines were not directed to South Plant the solids production decreased in proportion to the flow rate. The flows from the York and North Creek lines will be directed to Brightwater once commissioned. In the absence of observed data it was assumed that the net reduction in flow would represent Brightwater's impact on South Plant. The contribution of septage to the system was estimated based on characterizations made at other WWTPs as no characterization data were available for South Plant's septage, other than estimates of annual volumes. It is assumed that septage will continue to be received at South Plant and therefore the estimate is considered for informational purposes only, as septage solids are ultimately integrated into the observed raw sludge production numbers.

Based on the values presented in Table 4-3 an estimate of remaining digester capacity was made based on a variety of operating scenarios: parallel operation, series operation, and conditions with the largest unit out of service. In all cases the sludge storage tank (digester 5) was not considered in the process capacity assessment because of the variable-level operation and likely marginal benefit to degrade excess organic load. Using the organic and hydraulic loading criteria set forth at the start of this section, the residual capacity of the digestion process was evaluated for a variety of different loading conditions and operating scenarios for digestion and brown grease acceptance (see Table 4-4). Based on the data in Table 4-4 there appears to be capacity for brown grease co-digestion under the parallel operating regime but not the series operating regime.

Table 4-2. Summary of Current Loadings to South Plant with and without Brightwater Operations

Parameter	Observed data (includes York and North Creek Flows) [a]	Brightwater in operation [b]	Septage estimate [c]	Units
Average annual condition				
Total solids load	190,052	156,245	16,601	lb-TS/day
Total volatile solids load	160,802	132,326	8,915	lb-VS/day
Total flow	347,008	288,552	28,357	gpd
Maximum 30-day flow and load				
Total solids load	210,673	179,523	21,219	lb-TS/day
Total volatile solids load	179,163	151,404	11,394	lb-VS/day
Total flow	397,933	331,080	36,976	gpd
Maximum 20-day flow and load				
Total solids load	217,968	183,959	22,040	lb-TS/day
Total volatile solids load	185,545	155,648	11,836	lb-VS/day
Total flow	411,700	349,157	38,174	gpd
Maximum 14-day flow and load				
Total solids load	221,012	183,665	22,062	lb-TS/day
Total volatile solids load	188,097	155,866	11,847	lb-VS/day
Total flow	421,357	355,536	38,168	gpd
Maximum 7-day flow and load				

Total solids load	226,382	189,930	24,035	lb-TS/day
Total volatile solids load	192,101	160,681	12,907	lb-VS/day
Total flow	442,143	371,442	46,916	gpd
Maximum day flow and load				
Total solids load	250,367	211,320	40,119	lb-TS/day
Total volatile solids load	213,678	178,354	21,544	lb-VS/day
Total flow	469,000	392,256	77,628	gpd

a. Based on operational data provided by South Plant for 1/1/2007–7/31/2011.

b. Sludge production from York and North Creek flows assumed to be proportional to influent flow fraction.

c. Septage characteristics based on Brown and Caldwell work at Gloucester, Mass., WWTF, 2007, in the absence of sampling at South Plant, volumes of septage based on King County data, 1/1/2007 through 7/31/2011.

Table 4-3. Capacity of South Plant Digestion to Accept Brown Grease (Storage Tank Not Included)

	Capacity limitation based on OLR without York and North Creek	Capacity limitation based on SRT without York and North Creek
Digester configuration	VS load (lb-VS/day)	Flow (gpd)
Parallel: all units in service		
Average annual	119,089	582,206
Maximum 30-day	100,011	539,678
Maximum 20-day	95,767	521,601
Maximum 14-day	95,549	515,222
Maximum 7-day	90,735	499,316
Maximum day	73,061	478,503
Parallel: one unit out of service		
Average annual	56,235	408,055
Maximum 30-day	37,157	365,526
Maximum 20-day	32,914	347,450
Maximum 14-day	32,696	341,070
Maximum 7-day	27,881	325,165
Maximum day	10,207	304,351
Series: all units in service		
Average annual	56,235	582,206
Maximum 30-day	37,157	539,678
Maximum 20-day	32,914	521,601
Maximum 14-day	32,696	515,222
Maximum 7-day	27,881	499,316
Maximum day	10,207	478,503
Series: one unit out of service		
Average annual	NA	408,055
Maximum 30-day	NA	365,526
Maximum 20-day	NA	347,450
Maximum 14-day	NA	341,070
Maximum 7-day	NA	325,165

Maximum day	NA	304,351

NA: No residual digester capacity available to accept FOG (based on max OLR = 180 lb-VS/1,000-ft^3-day and min SRT of 15 days).

Typically Brown and Caldwell will evaluate a mesophilic digesters based on the maximum 14-day loading condition because it most closely matches the critical design and operating condition of maintaining an average HRT above 15 days. The County has noted that its biosolids product deteriorates below an HRT of 20 days and selected an allowable HRT of 20 days. For this analysis, the minimum HRT is 20 days, and the maximum OLR will be based on the maximum 14-day condition as it matches our recommended maximum condition. Table 4-4 summarizes the loads used to assess digester capacity, assuming a parallel digestion operating scenario.

Table 4-4. Capacity of South Plant to Accept Brown Grease Under Parallel Digester Operation

	Capacity limitation based on OLR without York and North Creek	Capacity limitation based on SRT without York and North Creek
Digester configuration	VS load (lb-VS/day)	Flow (gpd)
Parallel: all units in service		
Average annual	119,089	582,206
Maximum 20-day	95,767	521,601
Maximum 14-day	95,549	515,222
Parallel: one unit out of service		
Average annual	**56,235**	**408,055**

NA: No residual digester capacity available to accept FOG (based on max OLR = 180 lb-VS/1,000-ft^3-day and min SRT of 15 days).

The available capacity of the digestion process can be set by either maximum loading conditions as discussed previously or an out-of-service condition at average annual conditions. The controlling condition is the out-of-service condition, which allows the County to take a digester down for routine maintenance, such as cleaning. Based on the data presented in Table 4-4, the digestion process currently has approximately 56,200 pounds volatile solids per day (lb-VS/day) loading capacity remaining, with the projected consumption of digester capacity based on King County growth projections, shown in Figure 4-2. Based on hydraulic capacity, approximately 408,000 gpd of digester feed is currently available, at the average annual conditions with one unit out of service. Figure 4-3 plots the consumption of hydraulic capacity based on the projected increase in raw sludge production by the County.

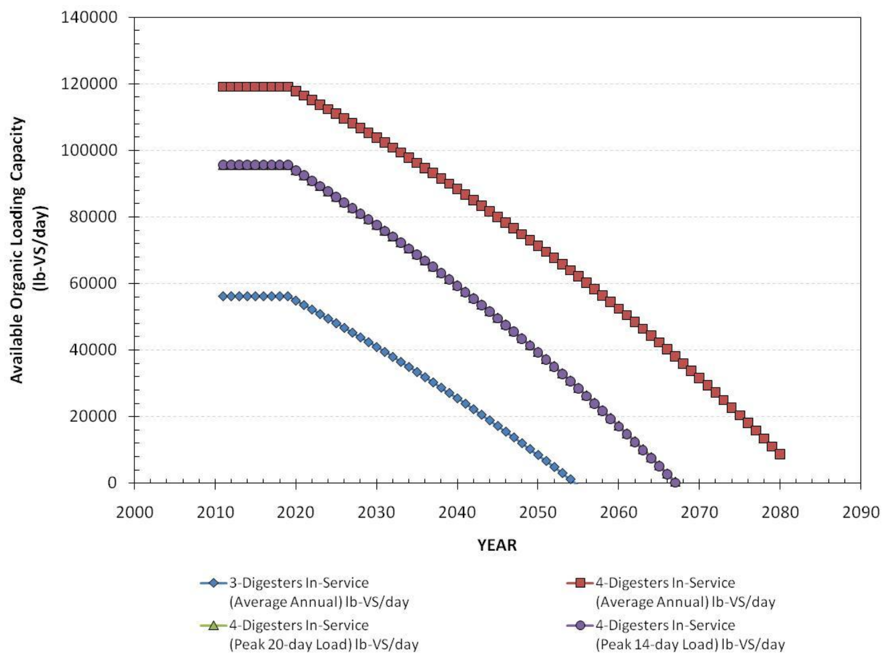


Figure 4-2. Projected utilization of digester organic loading capacity at South Plant by sewage sludge only

(Assumes 0% growth until 2019 and 1% annual thereafter)

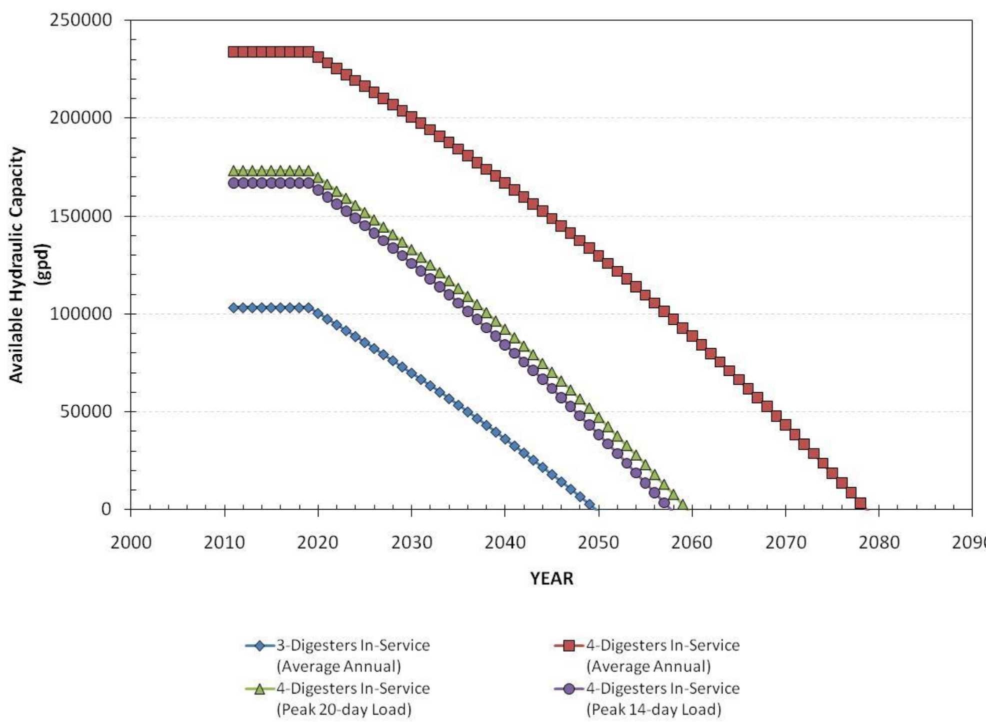


Figure 4-3. Projected hydraulic loading capacity utilization at South Plant by sewage sludge only

(Assumes 0% growth until 2019 and 1% annual thereafter)

4.3 Capacity Utilization with Fats, Oils, and Grease Acceptance

The available capacity of the digestion system can either be preserved for future growth or utilized for bioenergy production through co-digestion. Regardless of the digester capacity available, we suggest that the loading of FOG to a digester be limited to about 30 percent of the volatile sludge load, without pilot and stress testing the system. Work by Suto et al. (2006) demonstrated on the bench scale that when the proportion of FOG load increased from 35 percent of the load to 50 percent of the load, deterioration was observed in the biogas recovery. The other impact of FOG addition would be the increase in hydraulic load. As noted in the previous sections the concentration of FOG can vary greatly depending on pretreatment and skill of the hauler to remove the material and minimize water uptake from the interceptor or trap.

Based on the conditions defined in the previous section, remaining digester capacity, and the recently discussed limitations of FOG with digestion, projections of FOG acceptance on digester capacity at South Plant were evaluated. In this analysis it was assumed that in the first years of operation, sludge loading would increase by 0 percent (current to 2019) and 1 percent per annum (2020 on), per King County direction. It was further assumed that FOG availability would increase at a rate similar to sludge production as, because it is primarily generated by activities such as cooking and food processing, grease production is inherently tied to population.

Assuming a maximum FOG load of 30 percent of the current sludge VS load at average annual conditions, South Plant could receive up to 39,698 lb-VS_{FOG}/day, in the first year of operation. Under the estimated current loading conditions there is sufficient capacity to accept FOG loads up to 30 percent of the average annual sludge VS load.

While the system is capable of accepting the maximum FOG load under current conditions, it will reduce the available capacity of the digestion system for future growth (sludge) by consuming the organic loading capacity. Figure 4-4 demonstrates the impact of different FOG loading rates, as a percent of sludge VS load, on the projected residual organic loading capacity. In instances where a sludge loading line intersects a FOG loading line the process will be at maximum organic loading for that specific set of conditions.

The impact of FOG on process conditions is not limited only to organic loading but also flow rate. FOG can range in solids concentration from 1 percent to greater than 20 percent total solids, as described in previous sections of this report. This will both consume digester hydraulic capacity and impact the heating demand on the digestion process (to be addressed in later sections).

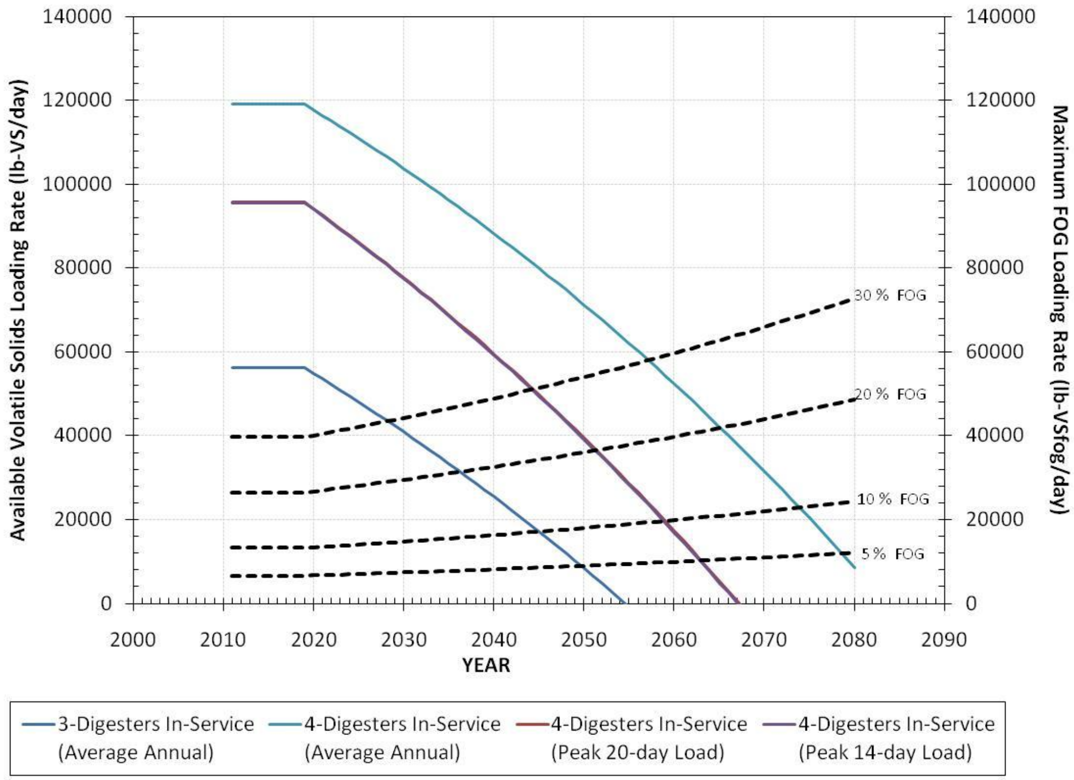


Figure 4-4. Consumption of digester organic loading capacity at different FOG loading rates

(Percent FOG represents percent of sludge VS load to the digester at average annual conditions)

Figure 4-5 and Figure 4-6 plot the change in hydraulic capacity with high FOG loading (20–30 percent of the volatile load) and lower FOG loading (5–10 percent of the volatile load) at different FOG solids concentrations. The data presented in these figures demonstrate the significance of FOG concentration on the capacity of the digestion system to receive supplemental feedstocks such as FOG and thus the ultimate scope of the program. It is apparent from the data that South Plant would need to receive brown grease at a minimum of 5 percent total solids to initiate a program at higher loading rates. Depending on the availability of brown grease and the capacity allocated to co-digestion, the ultimate scope of the program may influence the ultimate minimum concentration, as the lower loading conditions show an ability to accept a thinner FOG feed.

King County could utilize a scum thickener or other such device to increase the concentration of the brown grease loaded to the digesters. This will come at both a capital cost and a cost of BOD returned to the secondary system, increasing aeration demand and reducing biogas production, as the underflow will convey significant BOD back to the head of the plant. Along with the soluble fraction the heavy solids would be conveyed back as well to the primary clarifiers, increasing load to the clarifiers and DAFT system. However, these impacts must be balanced against the gain in digester capacity and the impacts on the heating of the FOG during storage and prior to digestion.

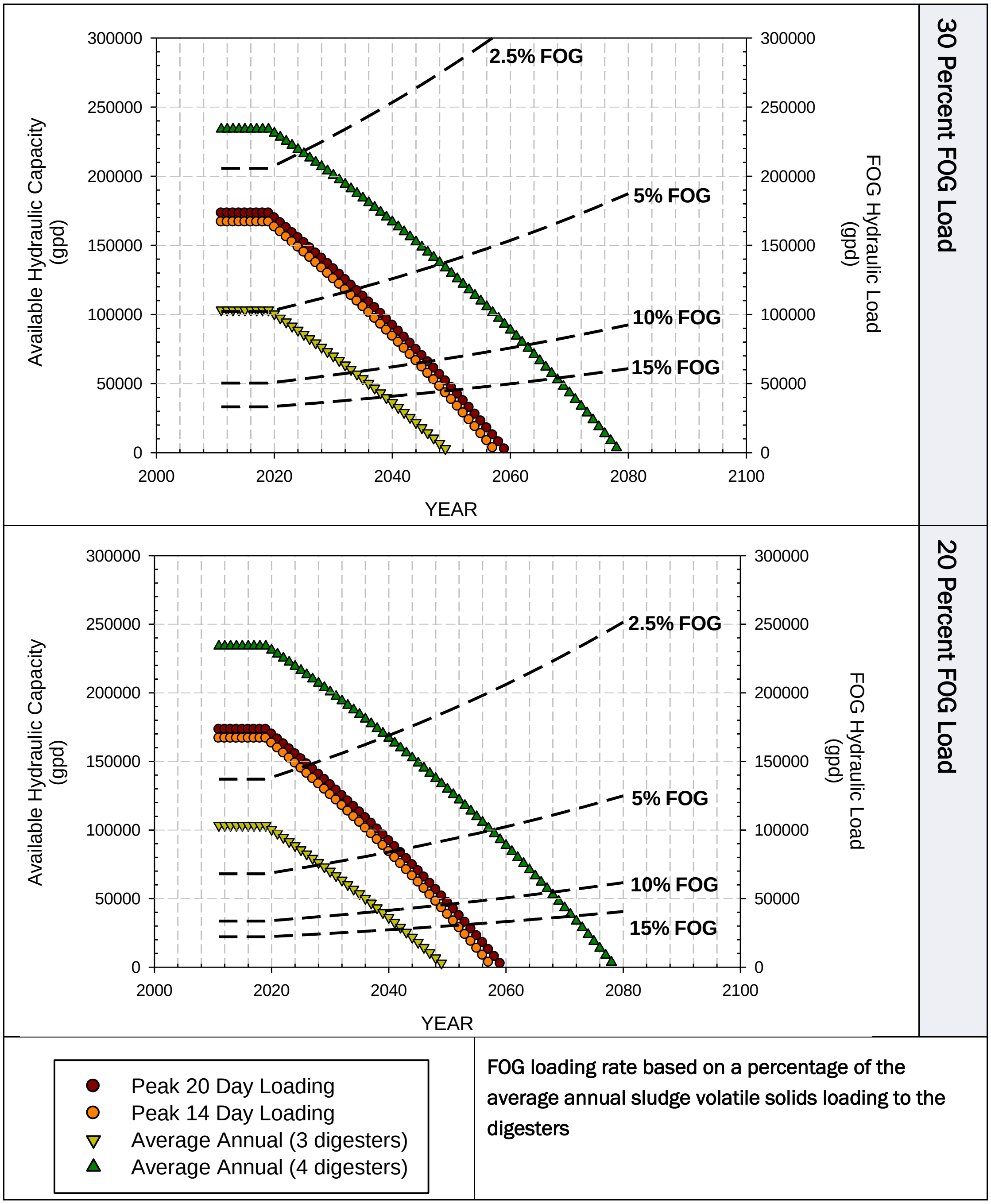


Figure 4-5. Influence of brown grease solids concentration on the hydraulic capacity of South Plant's digesters at FOG volatile solids loads of 20% and 30% of average annual sludge

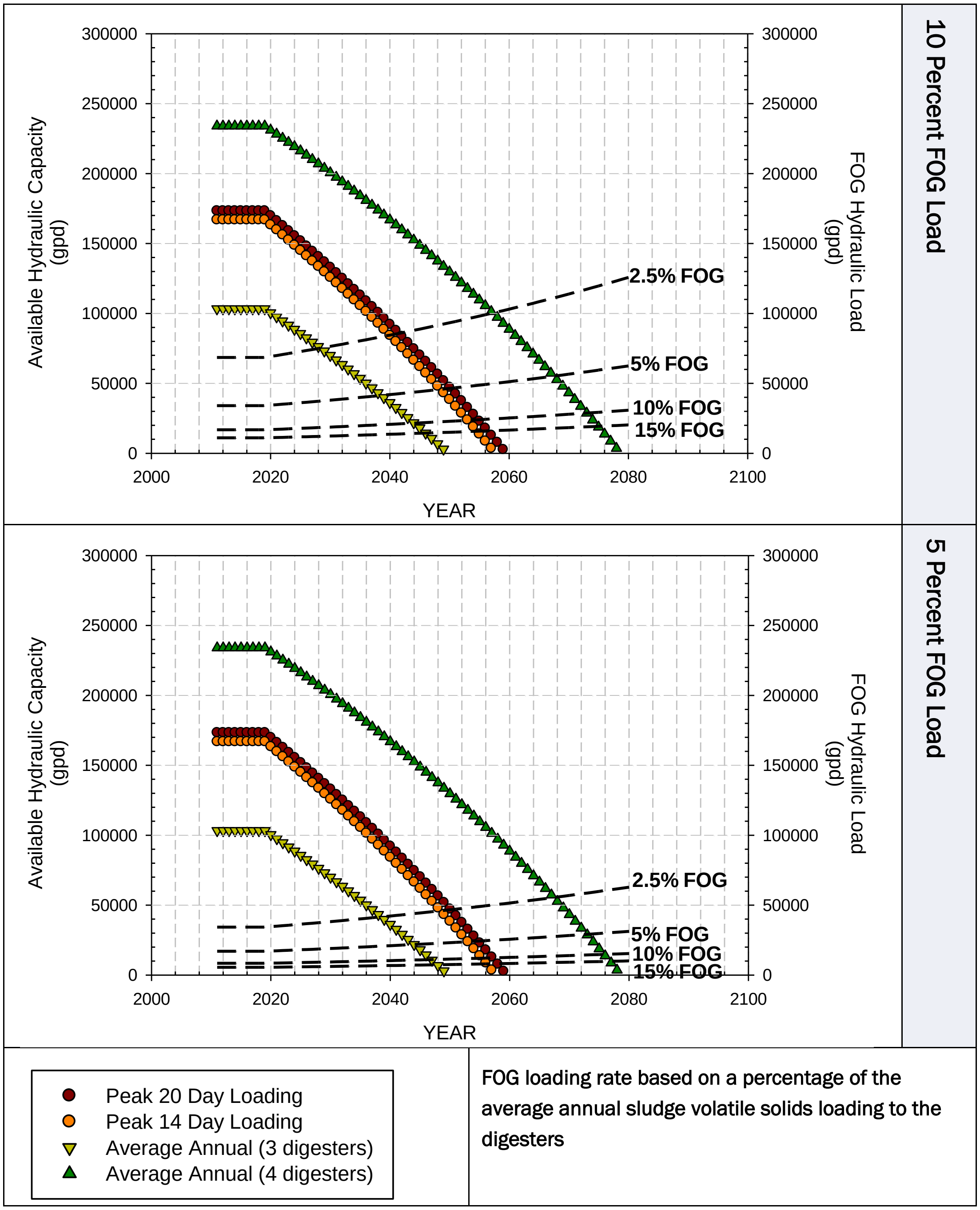


Figure 4-6. Influence of brown grease solids concentration on the hydraulic capacity of South Plant's digesters at FOG volatile solids loads of 5% and 10% of average annual sludge

More detailed analysis of the factors affecting the capacity of the digestion system to accept co-digestion substrates can be found in Figure 4-7 and Figure 4-8. These plots show the change in organic loading capacity and hydraulic loading capacity with time. In general the figures demonstrate that the digestion process will primarily be hydraulically limited when the solids concentration of the brown grease is below 8–10 percent total solids. It appears that the primary condition limiting FOG loading to the process is the one unit out-of-service condition, rather than a maximum loading condition.

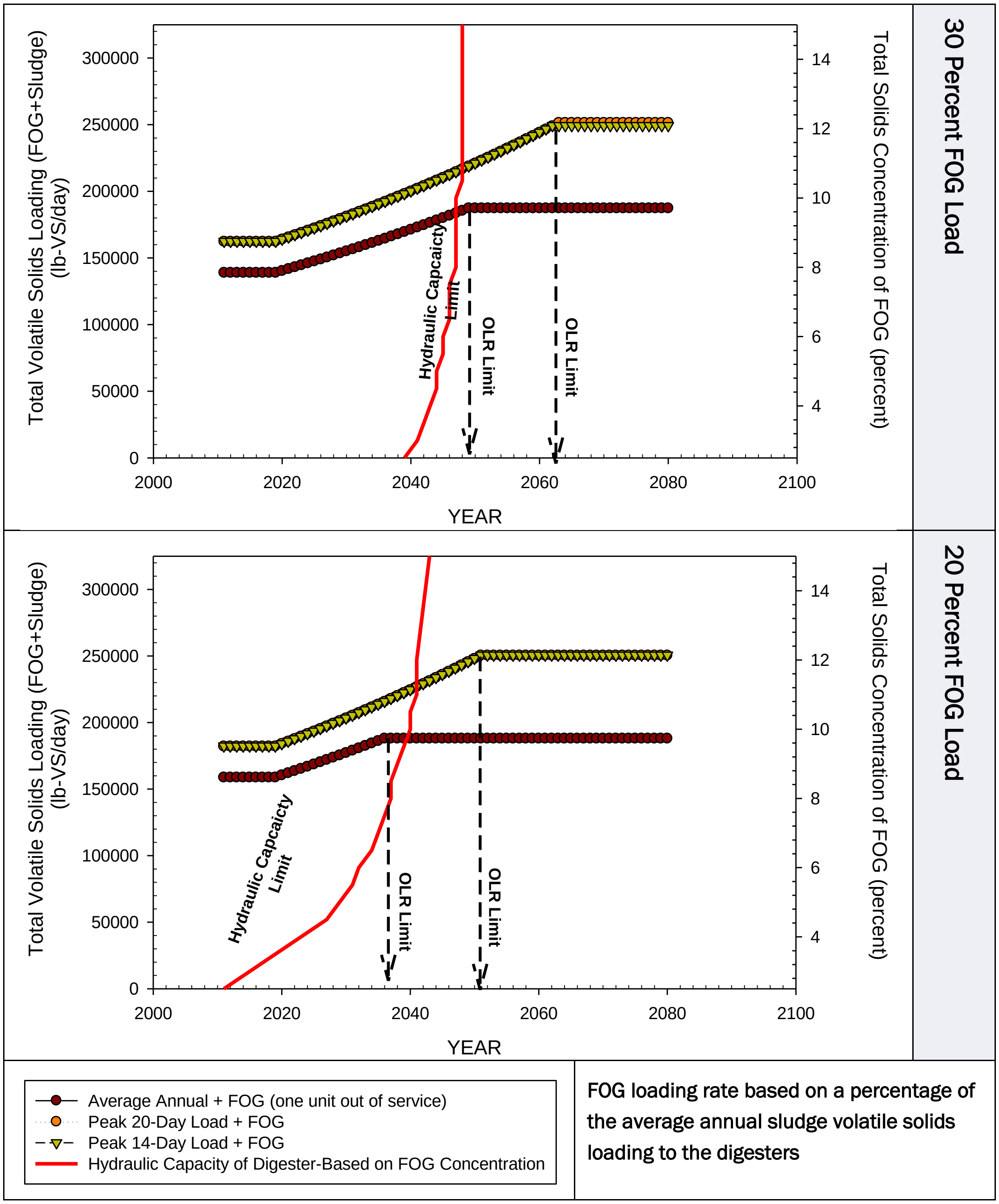


Figure 4-7. Organic loading capacity and hydraulic capacity of South Plant digesters receiving FOG at 20% and 30% of the organic load and varying concentrations

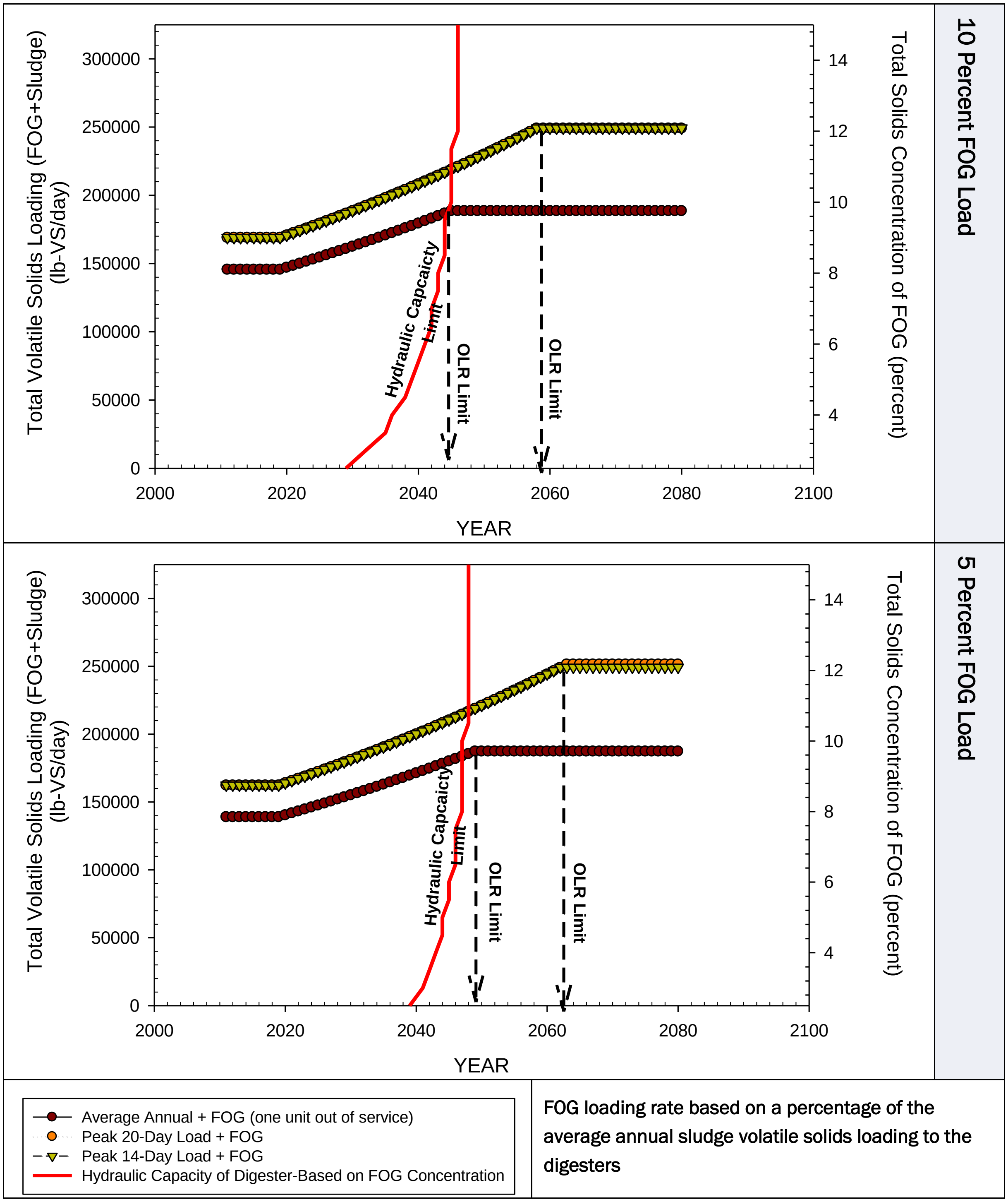


Figure 4-8. Organic loading capacity and hydraulic capacity of South Plant digesters receiving FOG at 5% and 10% of the organic load and varying concentrations

The data suggest that brown grease receiving is feasible at South Plant; however, the extent of the program and its ultimate benefits are more difficult to define. As an example the physical characteristics of the brown grease, such as concentration, have a significant impact on the scope of the program, especially as the organic load of FOG increases. While methods are available to thicken FOG, the limits of biological conversion of FOG to biogas are also not well defined. Through testing, an upper limit for FOG loading could be greater than the 30 percent recommended in this memorandum, which is based on current literature. Further, FOG, unlike sludge, appears to be more readily degradable once a population is acclimated. This may suggest that higher OLRs could be achieved in a full scale operating digester over time. A potential draw back to ever increasing proportions of FOG in the digester feed it the potential for long-chain fatty acid inhibition. Long chain fatty acids are released as the triglyceride ester bonds are broken. A stress test to determine the limits of brown grease co-digestion may be of benefit as it would set the boundary for the County as to ultimately how large a program it could support at South Plant.

4.4 Estimated Projected Biogas Production

The primary goal of a co-digestion program is to increase biogas production for beneficial use. Most substrates exhibit higher degrees of degradability than raw sewage sludges such that the overall production of biogas from the system can be increased. The amount of additional biogas that can be produced is based on the quantity of available substrates (FOG) as well as the available digester capacity, both hydraulic and organic loading-based. This section discusses different aspects of the biogas generation associated with co-digestion at South Plant. For all analysis conducted the average volatile solids destruction of the raw sludge observed at South Plant was used in combination with a biogas yield of 15 cubic feet of biogas per pound volatile solids destroyed (ft^3-biogas/lb-VSd). For FOG or brown grease, it was assumed that a volatile solids destruction of 85 percent could be achieved and a biogas yield of 18 ft^3-biogas/lb-VSd would be observed. In instances where there is variation from these values a notation is made.

4.4.1 Gross Biogas Production Potential from the Co-digestion of Brown Grease

Figure 4-9 presents average daily biogas production under different FOG portions of the total volatile load to the digester until the process reaches the maximum OLR. The points where the biogas production plateaus are the points at which the maximum process OLR is exceeded and the process risks destabilization with further loading. As the proportion of FOG load decreases the daily biogas production decreases, while available digestion capacity increases and capital improvements are deferred, such as additional digester construction.

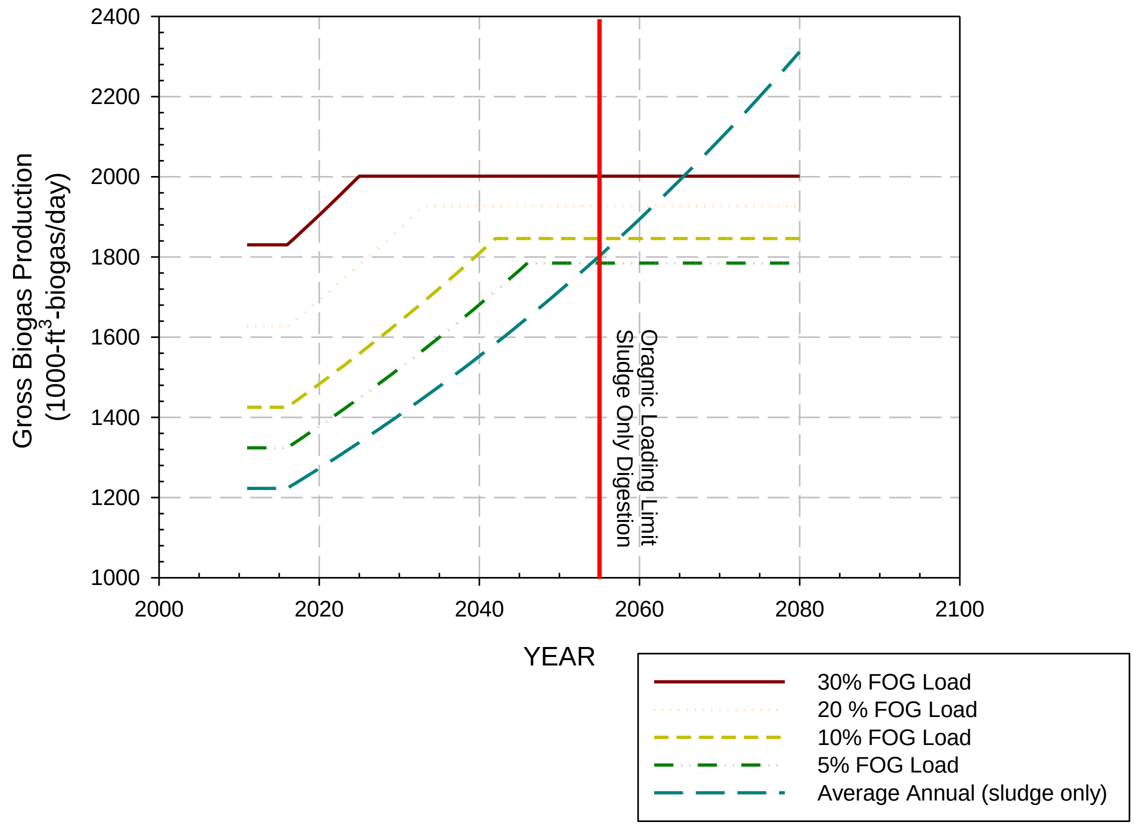


Figure 4-9. Average daily biogas production from South Plant digesters at different FOG loading rates

As with total system capacity the concentration of the brown grease received will impact the biogas potential of the system. Figure 4-10 correlates the average annual gross biogas production with the maximum organic and hydraulic loads at varying FOG concentrations. The data presented suggest that the FOG concentration will have a significant impact on the overall gross energy potential of a co-digestion program; understanding the local conditions and hauler practices may prove critical in estimating the overall potential of the program.

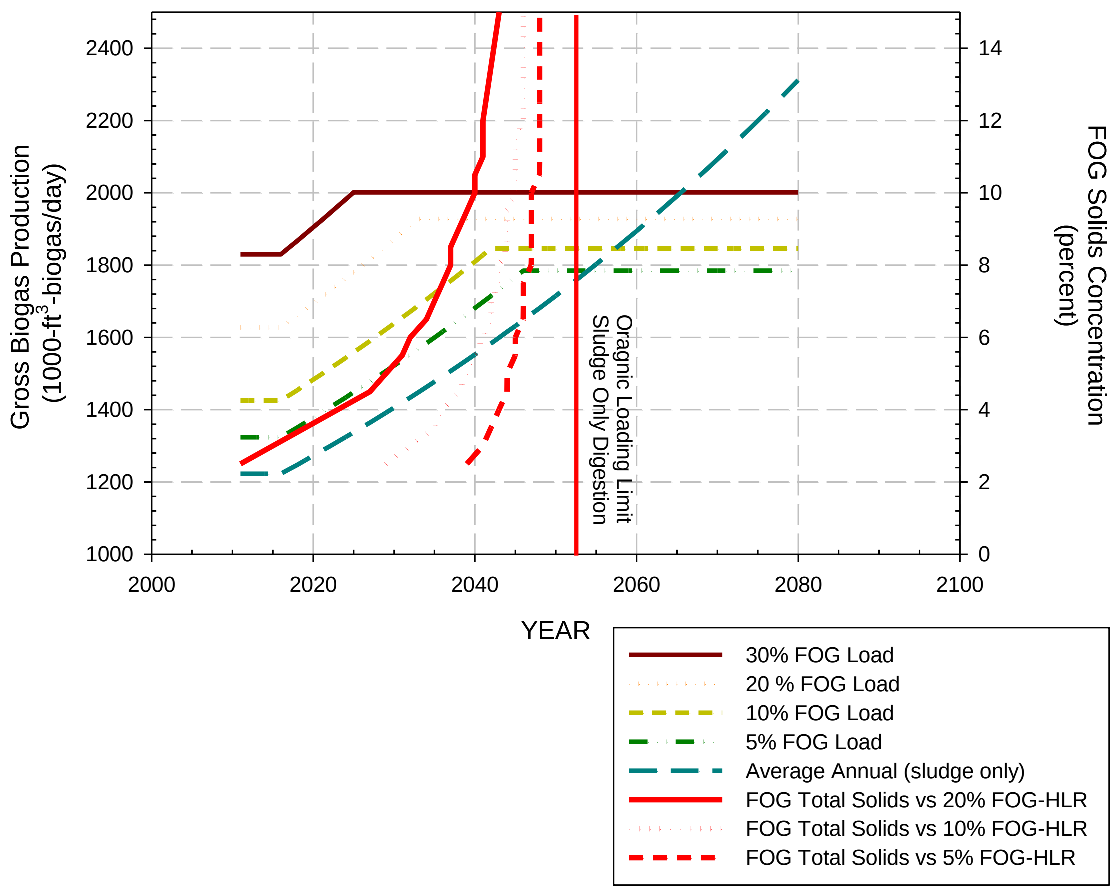


Figure 4-10. Relationship between gross biogas production and organic and hydraulic loading limits of FOG

However, the potential scope and benefit of the program will be impacted by the process parameters as well as the availability and concentration of the FOG accepted. The projections of gross average annual biogas production in Figure 4-10 were based on an assumed average biogas yield of 18 cubic feet of biogas (ft^3-biogas) per pound of volatile solids destroyed and a VSd of 85 percent. These parameters could be higher or lower depending on digester health and/or the biochemical properties of the FOG. Figure 4-11 demonstrates how first-year biogas production can vary with changes in biogas yield and VSd.

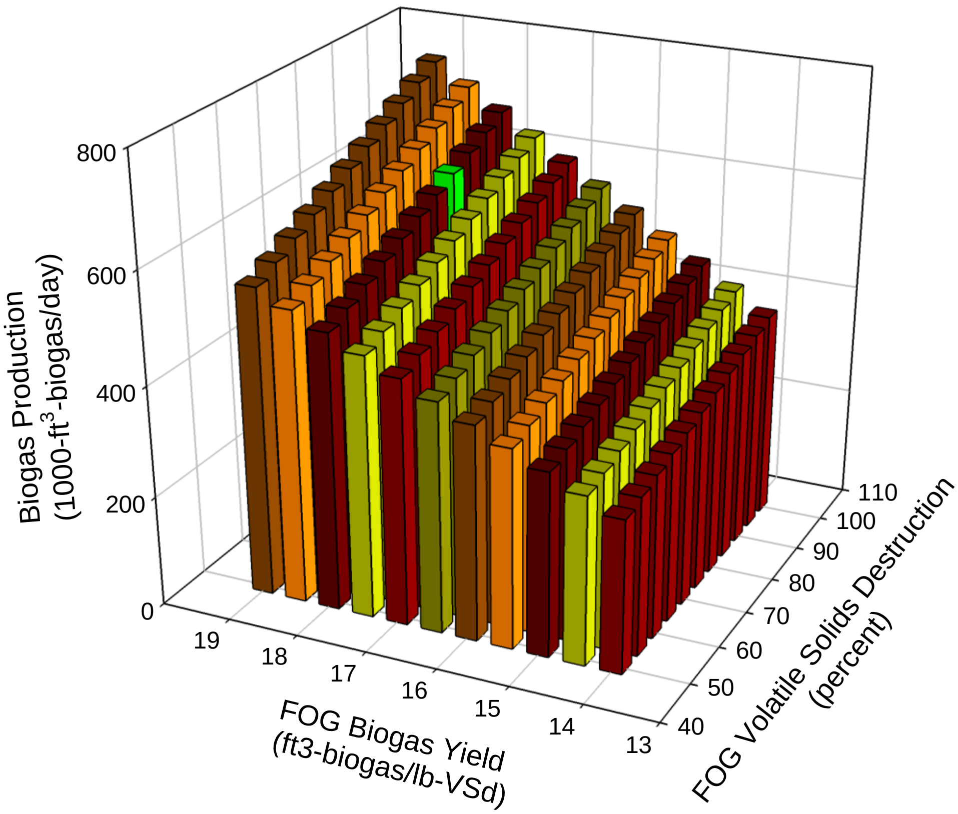


Figure 4-11. Change in biogas production with biogas yield and volatile solids destruction at 30% FOG loading for South Plant at average annual after Brightwater

(Green column represents assumed value for initial capacity assessments)

Another element of the biogas data that is variable is concentration of methane in the biogas. If an increase in methane content were to be observed from the addition of brown grease, the impact would be observed in the biogas end-use technologies as the energy content of the gas would increase, reducing the amount of gas needed to achieve a certain energy demand. Predicting biogas composition is difficult given the heterogeneity in the sludge and the substrates introduced into the digestion process. Li et al. (2002) indicated that lipid-rich materials produced the highest methane-content gas while carbohydrates theoretically produced the lowest methane concentrations in the biogas. This type of information is best gathered during a pilot testing period.

4.4.2 Net Biogas Production: Influence of FOG Concentration

FOG received by King County needs to be heated to facilitate digestion and convey the materials to the digestion process without line fouling, as is discussed in later sections. Heating of the FOG to digester temperatures will consume a portion of the biogas from the FOG. The extent of the consumption will be dependent on the FOG concentration; thinner solids reduce the amount of biogas available for energy production as heating demands increase. As an example, if King County accepts a 20 percent FOG load on a volatile solids loading basis at current loading conditions, with Brightwater in service, and a FOG VSd of 85 percent and biogas yield of 18 ft^3-biogas/lb-VSd, the net recovery of biogas can range from approximately 73–95 percent depending on FOG total solids concentration; see Figure 4-12.

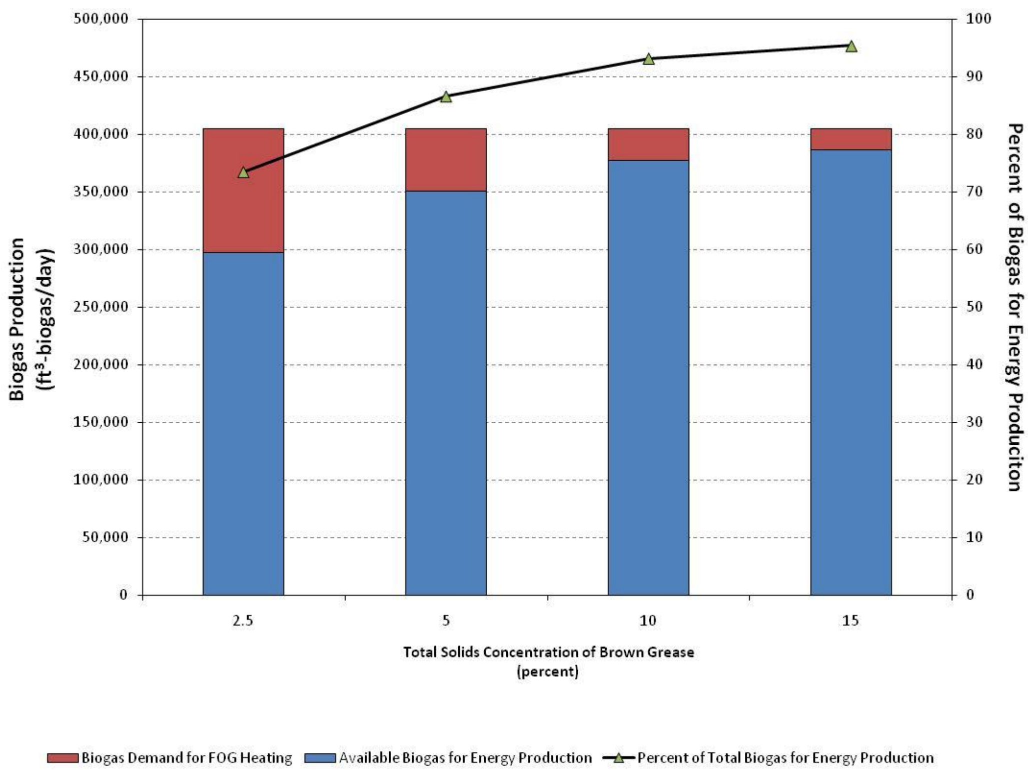


Figure 4-12. Impact of FOG concentration of biogas available for bioenergy production

(Assumes 20% VS load of FOG, 85% FOG VSr, 18 ft³-biogas/lb-VSd$_{fog}$, 61% methane content in gas)

Given the previously reported variability in FOG solids concentration and potential variability in biogas methane content, pilot testing may be warranted to better define future operating conditions.

5. Biogas Utilization Capacity

This section investigates the utilization facilities and emergency relieving capacity of the digester gas system at South Plant and its ability to accept additional digester gas produced by FOG co-digestion. The digester gas utilization facilities consist of the digester gas scrubbing equipment, a combined heat and power (CHP) system, and a hot water boiler. The scrubbed digester gas, or biomethane, can also be sold to PSE through the natural gas pipeline. The emergency relieving capacity of the system is provided by three WGBs on the plant site.

5.1 Current Gas Production

Current average annual and peak day biogas are estimated to be 1.22 and 1.65 million standard cubic feet per day (mm scfd), respectively. This estimated is based on the following assumptions:

- Biogas yield is 15 ft^3-bioagas/lb-VSd
- Volatile solids destruction of 62 percent

King County personnel have noted that hourly maximum digester gas production rates tend to be 10 percent higher than the average gas flows. The methane content averages 61 percent methane by volume dry and 38.5 percent carbon dioxide by volume dry.

5.2 Waste Gas Burners

Three WGBs are installed at South Plant. The burners are designed to be two duty and one standby. The three WGBs are enclosed Varec 244E burners with vendor listed capacities of 806,400 scfd at 8.5 inches WC. With two of the burners in operation, the vendor listed capacity of the system is 1.61 mm scfd.

Brown and Caldwell's current recommendations for sizing design capacities of WGBs are based on the size of the digester, the number of digesters, and the feeding method. For the South Plant application of four 100-foot-diameter digesters with continuous feeding, the recommended WGB(s) design should be sized to accommodate a peaking factor of 1.25 times the maximum daily gas production rate in the design year. The maximum daily gas production is significantly higher than the average annual gas production. The maximum daily gas production rate projected for South Plant is described in Section 4.

When assessing the existing design capacity of the WGB system, the peaking factor should be considered. The vendor listed capacity should be reduced by the peaking factor to establish the maximum daily gas flow rate for which the WGB system is adequate.

Including the peaking factor reduction of 1.25, the maximum daily digester gas flow rate that the WGB system is adequate for would be:

*WGB system maximum daily capacity (two burners) = 1.61 mm scfd*1/1.25=1.29 mm scfd*

If the third WGB were brought on line and considered a duty unit, then the system capacity would be:

*WGB system maximum daily capacity (three burners) = 2.42 mm scfd*1/1.25=1.94 mm scfd*

The WGB capacity is dependent on the digester gas pressure in the gas manifold. As digester gas pressure increases, so does the WGB system capacity. However, the WGBs must relieve with adequate capacity and at low enough pressure to keep the digester relief valves from opening. The digester relief valves are set to open at 14 inches WC. While it may be possible to set the WGBs to relieve at higher pressure than the current 8.5 inches WC to gain more capacity, a full analysis of the digester gas manifold would be required. The additional capacity that could be gained may be minimal.

5.3 Binax Water Solvent Digester Gas Scrubbing System

The digester gas scrubbing system manufactured by Binax is a water solvent type system that removes carbon dioxide, hydrogen sulfide, water, and other constituents to produce a pipeline-quality gas at about 98 percent methane by volume. This pipeline-quality gas is commonly referred to as biomethane or renewable natural gas. The Binax system comprises two process trains with a net capacity of 2.41 mm scfd of digester gas at the inlet. The net methane recovery is specified to be 95–96 percent; this means that 95–96 percent of the methane entering the system in the raw digester gas leaves the system as pipeline-quality biomethane. The system is designed for an inlet pressure of 4.0 to 7.0 inches WC. The biomethane can be sold directly to PSE by injecting into the 20-inch-diameter natural gas pipeline adjacent to the South Plant site or can be used in either the CHP system or the boiler.

The digester gas scrubbing system is contractually limited to a biomethane production rate of 1.3 mm scfd based on the contract with PSE. This is approximately the production capacity of the system at 2.41 mm scfd digester gas at the inlet with a methane content of 60 percent by volume on a dry basis and a methane recovery rate of 95 percent.

The effluent temperature may limit the digester gas scrubbing capacity by a marginal amount during summer. Effluent is used as the water solvent in the towers. Scrubbing capacity is inversely impacted by the water temperature sent through the scrubbing system. Effluent temperatures tend to vary from a high of 72 degrees Fahrenheit in late summer to a low of 52–54 degrees Fahrenheit in winter. The scrubbing capacity of the towers is therefore greatest in winter and lowest in summer. King County engineering estimates that the water flow rate can vary by up to 10 percent between the warmest and coldest effluent temperatures. Overall scrubbing system capacity reduction was not indicated, but it may be reduced by up to 10 percent on hot summer days.

5.4 Combined Heat and Power

The CHP system at South Plant consists of two gas turbine generators and a steam turbine. The gas turbines, made by Solar, are Centaur 40 models with an electrical power capacity of 3,515 kilowatts (kW). The specific fuel consumption (or heat rate) of the turbines is 12,240 British thermal units per kilowatt-hour (Btu/kW-hr) per King County engineering (assumed to be lower heating value) which equates to an electrical efficiency of 27.9 percent. The gas turbines operate on biomethane from the digester gas scrubbing system or natural gas. At full rated capacity, the digester gas flow rate required to power each turbine would be 2.08 mm scfd as produced by the digesters. This includes a 95 percent methane recovery rate from the Binax gas scrubbing system and an as-produced digester gas methane content of 61 percent by volume on a dry basis. The operation of both turbines would require a digester gas flow rate of 4.16 mm scfd. The digester gas scrubbing system is limiting flow to the gas turbines.

The 1.04-megawatt (MW) rated steam turbine can be driven by the recovered heat from the gas turbines and does not require additional digester gas for operation. King County engineering has noted that the capacity of this unit is likely closer to 0.9 MW because of previous maintenance issues.

5.5 Boiler

The hot water boiler is a Hurst Series 500 designed for a heat output of 11,700,000 Btu/hr. The original burner, which was able to burn digester gas, was replaced with one that can burn natural gas or biomethane. The efficiency of the boiler is estimated by King County engineering to be between 75 and 80 percent (higher heating value). At full rated capacity, the digester gas flow rate as produced by the digesters required to fuel the boiler would be 0.68 mm scfd. This includes a 95 percent methane recovery from the Binax gas scrubbing system and an as-produced digester gas methane content of 61 percent by volume on a dry basis. The digester gas scrubbing system is not limiting for gas flow to the boiler.

An electric-powered boiler is located in the main control building that was installed specifically to provide heat to the administration building. The boiler is also plumbed to provide heat to the HRS/HRR heat loop system. The Lattner BLR106500 hot water boiler nameplate shows an output of 500,000 Btu/hr.

5.6 Gas Handling System and Pressure Relief Valves

The scope for this study does not include an investigation of the gas handling system and pressure relief valves. Potentially either of these systems could be the limiting factor of digester gas production. The gas handling system includes the low pressure digester gas piping, and equipment and instrumentation such as sediment traps, flame arrestors and flow meters. The pressure drop through the gas handling system increases as digester gas flow rate increases. If the pressure drop gets too high, it may decrease the ability of the WGBs to relieve at rated capacity or may affect combustion. A pressure drop analysis should be completed to verify capacity of the gas handling system to transport digester gas.

The pressure relief valves on each digester are designed to relieve the peak digester gas production in order to keep pressure in the digesters below the structural design limits. The relieving capacity of the relief valves should be verified prior to the addition of FOG to the digesters.

5.7 Analysis of Results

The digester gas utilization facilities at South Plant are limited by either the digester gas scrubbing system or the boiler, assuming PSE line pressures do not exceed the limit for biomethane introduction. The digester gas scrubbing system treats gas for both the CHP system and the hot water boiler, and has the potential to be the limiting factor for biomethane utilization in the CHP system and the boiler. However, as identified in Table 5-1, the digester gas scrubbing system is the limiting factor for the CHP system only. The gas utilization facilities as-is could accept up to twice the amount of digester gas currently produced at South Plant. However, the overall digester gas system is limited by emergency relieving capacity. The relative capacities of the evaluated gas equipment are plotted against the projected sludge only biogas production from South Plant, Figure 5-1.

The WGBs are the limiting factor for digester gas production at South Plant. The plant needs to have emergency relief capacity for all of the digester gas produced in the event that the digester gas scrubbing system is not available. Based on Brown and Caldwell peaking factors for design, the existing WGB installation is limited to 1.29 mm scfd maximum day digester gas production with two burners as duty and 1.94 mm scfd with all three burners considered duty. The current average digester gas production is about 1.22 mm scfd and the current maximum day gas production (1.65 mm scfd) exceeds design capacity limits of the two duty burners and is 85 percent of the three duty burner system. In order to increase the average digester gas from FOG or sludge, the capacity of the WGB system should be increased. We recommend evaluating and confirming the pressure drop in the gas system as it may be possible to increase the pressure setting at the waste gas burners and increase their capacity.

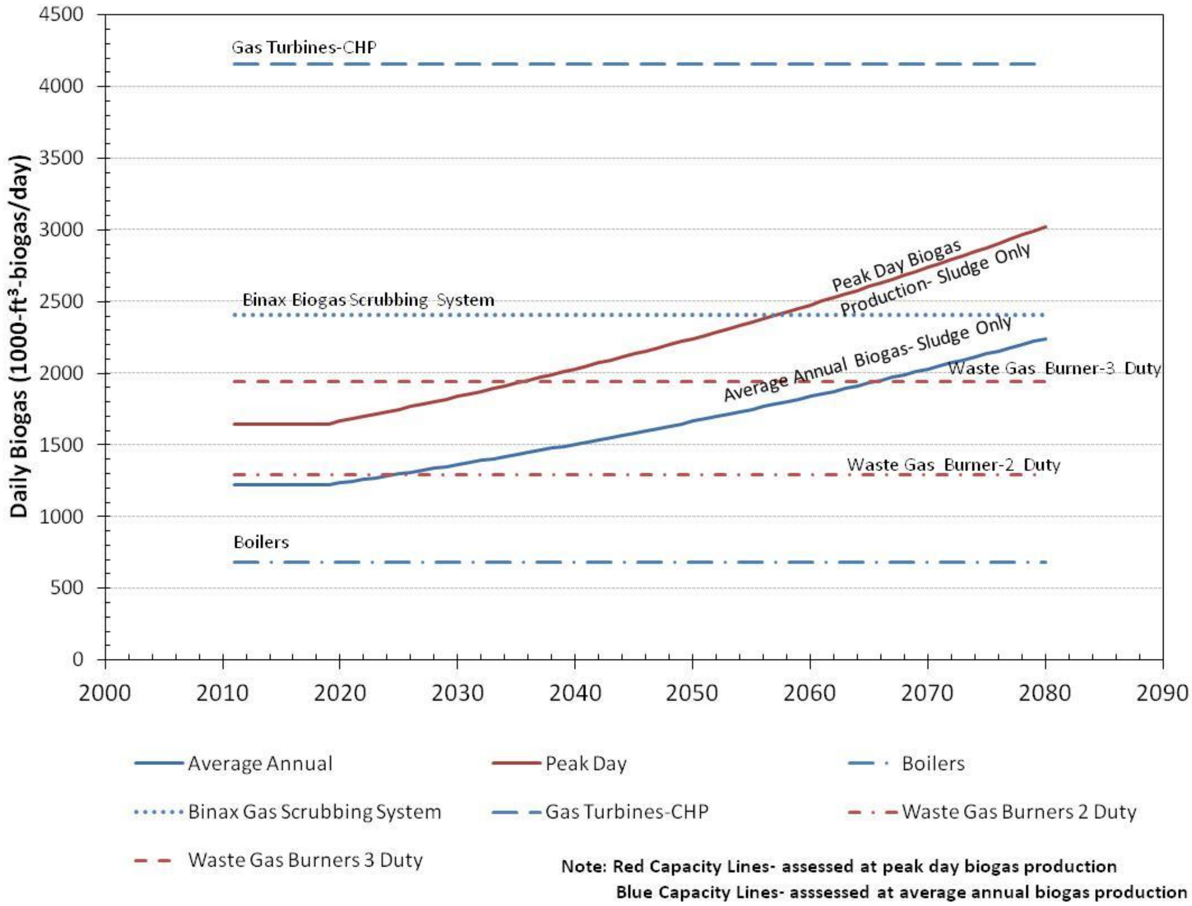


Figure 5-1: Capacity of Biogas Utilization Technologies at South Plant Relative to Projected Sludge-Only Biogas Production

Table 5-1. Digester Gas Capacities and Limiting Factors

Equipment	Digester gas utilization capacity, mm scfd	Emergency relief design capacity at maximum day gas flow, mm scfd [b]	Limiting factor
Waste gas burners (two duty)	N/A	1.29	Waste gas burners
Waste gas burners (three duty)	N/A	1.94	Waste gas burners
Binax system: digester gas scrubbing	2.41 [a]	N/A	Gas scrubbing
Gas turbines: CHP	4.16	N/A	Gas scrubbing
Boiler	0.68	N/A	Boiler

a. May be reduced by effluent temperatures in summer.

b. Includes reduction of 1.25 for design peaking factor.

6. Impacts on Nutrient Recycling and Biosolids Production

The digestion of FOG at South Plant will not only impact the biogas production at the facility but also potentially increase nutrient load to the secondary system and biosolids for disposal. This section discusses the potential changes in these two program parameters.

6.1 Nutrient Recycling from FOG Addition

Currently South Plant does not have a nutrient limit (nitrogen or phosphorus) as part of its National Pollutant Discharge Elimination System (NPDES) permit. However, there is the potential that a nitrogen limit may be imposed on wastewater plants that discharge to specific portions of Puget Sound. The introduction of additional organics and their associated nutrients from a co-digestion program could increase the load of nitrogen returned to the secondary system in the dewatering return streams. A literature review found that that the amount of nitrogen in FOG can vary greatly from a TKN of 1,000 mg-N/kg-sample to 10,200 mg-N/kg-sample. The concentration would likely vary depending on the material source, processing, and collection practices used.

Using these two concentrations as boundary conditions an estimate of additional nitrogen returned to the secondary system was made at average annual conditions. Given the potential complexity of nitrogen uptake and use and the limited amount of data available on FOG nitrogen partitioning several simplifying assumptions were made in this analysis:

- It was assumed that nitrogen, released from FOG, was proportional to the VSd.
- The observed TKN from the literature represented organic nitrogen and soluble nitrogen (ammonia and other species) were negligible.

Based on these simplifying assumptions an estimate of the potential impacts of FOG digestion on return-stream nitrogen on a pounds per day basis was made and summarized in Table 6-1 for varying loading rates of FOG on a volatile solids basis.

Table 6-1. Estimated Nitrogen Return in Centrate Due to FOG Co-digestion at South Plant at Varying Loading Rates

			Higher FOG N-content (lb-N/lb-VS): 0.052			Lower FOG N-content (lb-N/lb-VS): 0.034		
Substrate	FOG VS loading (%)	FOG loading (lb-VS/day)	Sludge N load (lb-N/day)	FOG N load (lb-N/day)	N load increase (%)	Sludge N load (lb-N/day)	FOG N load (lb-N/day)	N load increase (%)
Raw sludge	0	0	5,425	0	0	5,425	0	0
Raw sludge + FOG	5	6,616	5,425	294	5	5,425	191	4
Raw sludge + FOG	10	13,233	5,425	589	11	5,425	382	7
Raw sludge + FOG	15	19,849	5,425	883	16	5,425	574	11
Raw sludge + FOG	20	26,465	5,425	1,178	22	5,425	765	14
Raw sludge + FOG	25	33,082	5,425	1,472	27	5,425	956	18
Raw sludge + FOG	30	39,698	5,425	1,767	33	5,425	1,147	21

Sludge loading to digesters based on average annual condition, 132,325 lb-VS/day, assuming Brightwater in-service.

Assumed the following characteristics for sludge: TS = 6.4%, VS/TS = 84.9%, VSr = 61.6%, SG = 1.02, and TKN = 3,700 mg-N/kg-sludge.

Assumed the following characteristics for FOG: TS = 21.2%, VS/TS = 91.9%, VSr = 85%, SG = 1.04.

The data in Table 6-1 show that the impact of FOG co-digestion is dependent upon the scope of the program, how much is accepted, and the biochemical characteristics of FOG being collected and delivered to the plant. The incremental increase in nitrogen return from FOG co-digestion could impact South Plant if the County moves to nitrification and/or denitrification, increasing aeration and alkalinity demand, or carbon demand, respectively.

Further complicating the estimate of FOG impacts on nitrogen return in the centrate is the potential impact of synergistic digestion enhancement. As discussed in previous sections, synergistic digestion is thought to occur with the sufficient addition of co-digestion substrates, where the sludge solids digest better in the presence of the substrates than they do alone. If real, this phenomenon results in increased biogas and reduced biosolids production, both benefits. However, improved sludge digestion would also increase the return of ammonia in the centrate, further impacting the secondary process.

Given the potential for a nitrogen limit on Puget Sound, it is recommended that nitrogen levels in the FOG and digester effluent be evaluated during any pilot study, to ensure that the net benefits of the program are truly accounted for. Given the current significant lack of reliable characterization data and the inherent heterogeneity of the substrate itself a longer-term study would provide improved clarity on the subject. As part of any future analysis a nitrogen balance around the digestion process, with and without FOG addition, should be developed at different loading rates to ascertain the overall impact and better detect potential synergistic benefits from co-digestion.

6.2 Impacts of FOG on the Biosolids Program

The impacts of FOG addition on biosolids production are as nebulous as the nutrient impacts due to varying rates of FOG biodegradation and the potential for synergistic effects. Figure 6-1 provides an estimate of the additional biosolids production from FOG at 85 percent VSd, 92 percent volatile content, and no synergistic effects for a variety of FOG loading conditions. Depending on the scope of the program an additional 2,000 pounds total solids per day (lb-TS/day) to greater than 10,000 lb-TS/day could be observed, under the assumed conditions.

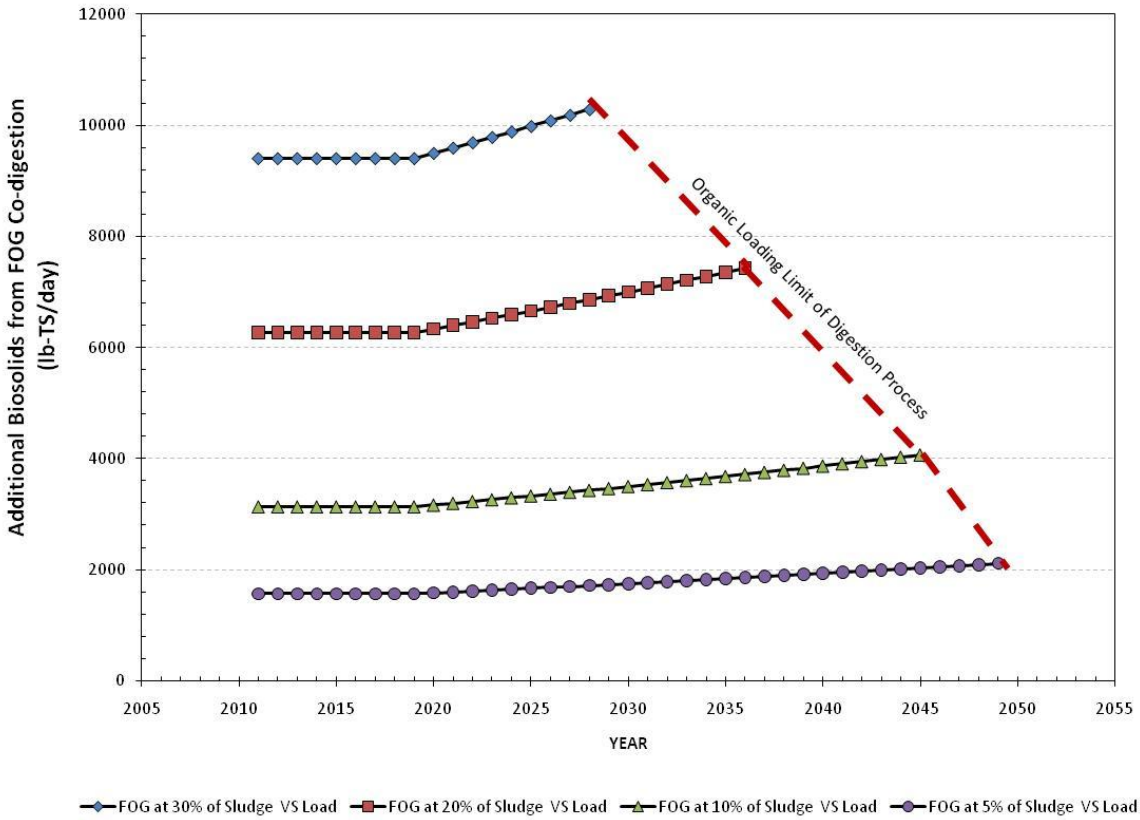


Figure 6-1. Estimated additional biosolids production from FOG co-digestion at South Plant at varying loading rates

(Assumes FOG VSr of 85% and volatile content of 92%)

Factors impacting the biosolids projections include the potential for synergistic effects as previously mentioned as well as the observed VSd and the VS content of the received FOG. Volatile content of FOG has been reported to range from approximately 67–100 percent in the literature. Figure 6-2 demonstrates the impact of variation in VSr and volatile content of the FOG on a program receiving FOG at 30 percent of the current average annual VS load. Under this analysis the boundary conditions for additional biosolids could be zero to approximately 55,700 lb-TS/day of additional biosolids in the first year of operation, depending on the conditions selected.

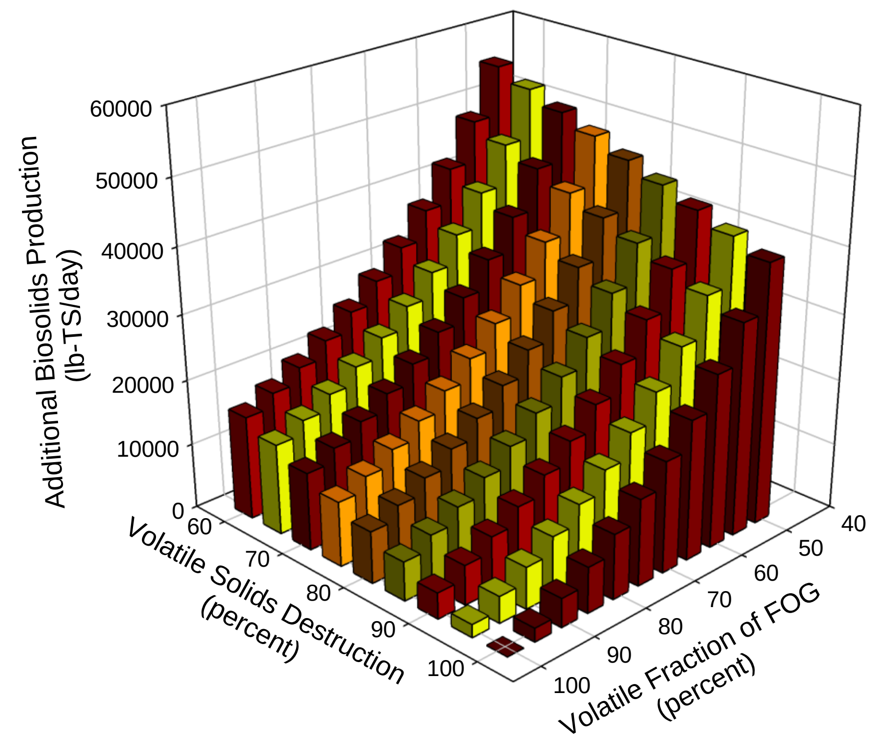


Figure 6-2. Sensitivity of additional biosolids production to FOG characteristics at 30% of the average annual volatile load at South Plant, 2011

(Assumes Brightwater is in service)

As observed in other sections a true measure of additional biosolids will likely require the piloting of the process given the limited long-term operating information available for co-digestion facilities in North America. There is also a lack of data on the impact of co-digestion on the cake solids concentrations generated during dewatering. Minor changes can result in significant added costs or savings for large utilities on an annual basis, if dewatering deteriorates. Understanding these impacts as well as overall additional total solids is recommended.

Biosolids handling and aesthetic quality must be considered as well. King County currently beneficially uses all of its biosolids at different land application sites. Understanding if there are changes in biosolids characteristics due to co-digestion would be critical to maintaining beneficial use alternatives and capital investments needed to handle a change in characteristics.

7. Additional FOG Handling Process Considerations

The digesters at South Plant appear to have sufficient available capacity to accept brown grease to increase bioenergy production. This section provides a qualitative discussion on issues with grease receiving and the pros and cons of moving forward under full program implementation or pilot scale with expansion to full-program at a later date.

Several aspects of grease acceptance at a WWTP need to be considered, whether at the pilot scale or full scale. This section provides a brief summary of lessons learned either from literature or firsthand experience with pilot testing of brown grease in digestion systems.

7.1 Compliance with Biosolids Regulations

FOG should be collected and tested periodically. Some utilities test all loads while others collect a sample from all haulers, test a select few, and store the samples in case of a problem. This process allows them to go back and conduct diagnostics to see if there was any contamination from the FOG haulers that could be the cause of a process upset or non-compliance event.

Compliance with biosolids regulations requires testing for metals or other contaminants and also screening the materials. The Department of Ecology, under the “Inerts Rule,” requires that any biosolids that are to be land-applied must be screened through a 3/8-inch or smaller opening prior to land application. The County could screen the digested sludge prior to centrifugation or screen grease during the receiving process.

Based on our experience with a pilot test, we recommend that the grease be screened prior to digestion. Figure 7-1 shows residual debris collected from a FOG storage tank mixed with a chopper pump. The plastic-like material survived the process and would eventually be deposited in the digester or could create blockages in the digestion system, such as at spiral heat exchangers. This approach also reduces the size of equipment needed to process the effected material.

Figure 7-1. Debris in brown grease loads following pilot testing period

7.2 Heating of FOG

Grease can undergo dramatic changes in physical properties with changes in temperature. At most ambient temperatures grease forms as a solid that precipitates on surfaces. This is a critical factor in the formation of sewer blockages, and is why many municipalities limit the temperature of water entering a grease interceptor when discussing best management practices. Figure 7-2 illustrates this property in a basket strainer at a pilot facility in California. The cool grease blocked the strainer, preventing the grease from flowing to the storage tank. Heating grease will be critical to keeping a receiving station operating well and the pipes clear of blockages. Some utilities have reported success using hot sludge flushing of grease laden lines to scour and transport materials to the digester, reducing the line coating of grease.

Figure 7-2. FOG blockage in a basket screen

7.3 Grit and Abrasives

Grease traps and interceptors are intended to receive only grease and food waste products; however a significant amount of abrasives have been observed with this material as well. Figure 7-3 shows the wear on the stator of a progressing-cavity pump used during pilot testing of FOG co-digestion. The rotor depicted was 7 weeks old at the time of failure. Protecting equipment can reduce overall maintenance costs and operator attention.

Figure 7-3. Impact of grit on a progressing-cavity pump used for brown grease pilot testing

7.4 Mixing

Mixing is a critical factor in the success of a co-digestion program. Inadequate mixing in the digesters and at the receiving facility can present a myriad of different operating challenges.

Inadequate digester mixing can lead to formation of scum layers, which can either escape floating-cover digesters through the annular space around the cover or reduce the active volume of the digesters. Inadequate mixing in a digester can lead to short-circuiting, which will result in a loss in biogas production as materials will not be degraded. The potential also exists for a deterioration of the quality of the biosolids aesthetics as undegraded substrate may degrade during biosolids transport or land application, resulting in nuisance odor complaints. In the initial discussions with King County it was noted that a recent dye tracer study indicated 95 percent active volume, an indication of adequate mixing.

Mixing can also be important in receiving and storage facilities of co-digestion substrates. Adequate mixing not only homogenizes what are typically heterogeneous loads but also evens the load going to the digesters over time. Brown grease is non-polar in nature and separates from water if not adequately mixed, as shown in Figure 7-4. This separation can result in a stratification of the load to the digesters, with the weak liquid phase being introduced first and then a much heavier load coming with the floating material. This can impart some instability in the process and especially biogas production. Any biogas sent to the flare from co-digestion is lost revenue. Therefore, a balanced loading approach to the digesters is recommended, constant with both time and load.

Figure 7-4. Stratified brown grease in an under-mixed tank

7.5 Process Considerations

The loading of brown grease to digesters should be as consistent as possible. The high degradability and volatile content of brown grease can produce spikes in biogas if slug loaded to a digester, beyond those observed with a similar volume of sludge. Biogas production that exceeds demand will end up being flared and the potential revenues lost, as shown in Figure 7-5. Slug loading the system too heavily can also lead to inadvertent digester upset as the process approaches it loading capacity. Managing FOG loading to the digesters will be important to the overall success of the program during execution.

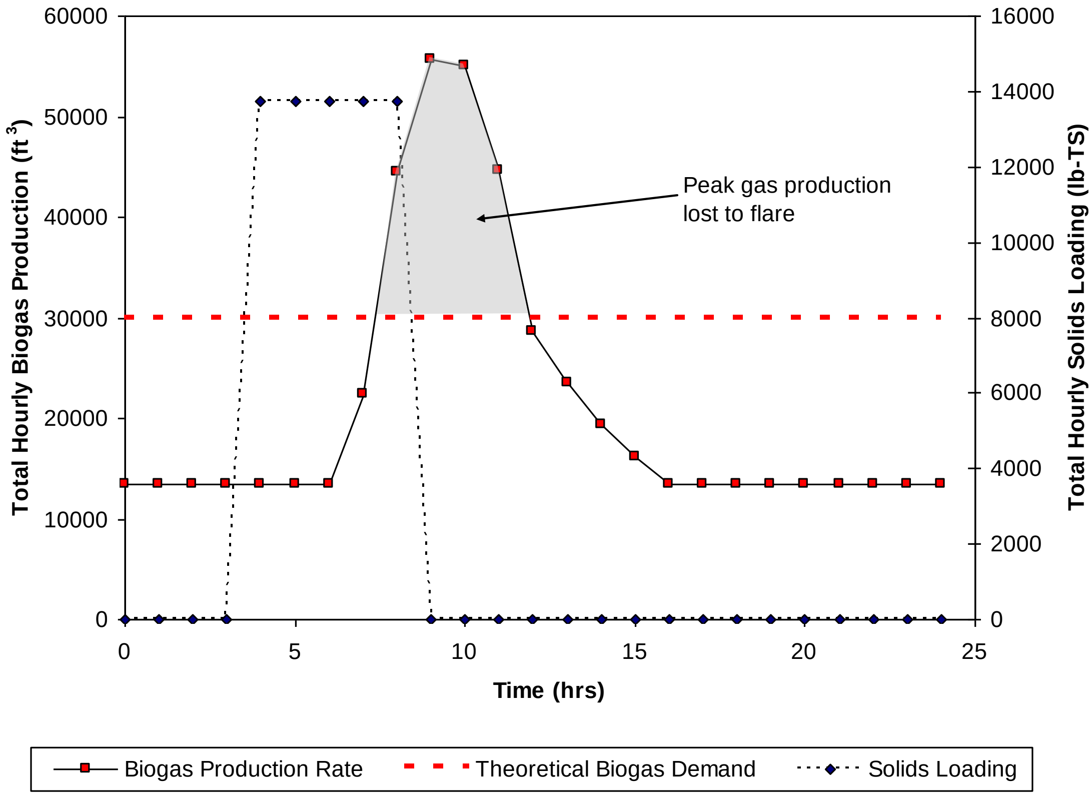


Figure 7-5 Theoretical example of biogas peaking due to slug loading of digesters and the potential for loss of energy

Note: Shaded region represents peak gas production directed to flares; theoretical biogas production and demand is not intended to represent actual conditions at South Plant, it is for illustrative purposes only.

When adding new substrate to a digester it should be done incrementally allowing the population to acclimate to the change in substrate composition and loading conditions. Not allowing the process to acclimate and populations to adjust to the loading conditions could result in process upset. This is typically achieved by slowly introducing increasing amounts of substrate with time.

8. Summary and Recommendations

This preliminary capacity analysis indicates that South Plant has sufficient digester capacity to accept brown grease. The process is limited by the largest unit out of service condition at average annual, rather than a peak loading condition. Under the limiting operating condition the following capacity values apply:

- Available digester organic loading capacity: 56,200 lb-VS/day
- Available hydraulic loading capacity: 408,000 gpd
- Current maximum recommended brown grease load: 39,698 lb-VS_{FOG}/day

Further, it appears that the major biogas end-use technologies have sufficient remaining capacity to beneficially utilize the added biogas, with the biogas scrubbing system and boilers running out of capacity first.

- Capacity of waste gas burners, 2 duty: 1.29 mm SCFD at peak day biogas production
- Capacity of waste gas burners, 3 duty: 1.94 mm SCFD at peak day biogas production
- Capacity of Binax biogas scrubbing system: 2.41 mm SCFD
- Capacity of gas turbines: 4.16 mm SCFD
- Capacity of gas fired boilers: 0.68 mm SCFD

The waste gas burners at South Plant appear to have begun to become limited in their capacity for emergency relief of biogas, which will only be exacerbated by the addition of brown grease to the digesters as the gas production could increase significantly. Further it is recommended that the entire gas handling system be evaluated for its capacity to convey additional biogas and safety equipment's capabilities to release biogas when needed.

Analysis of the process impacts of brown grease demonstrated that there is a lack of consensus on appropriate values to be used in a robust economic and process evaluation for co-digestion. While estimates may be used to understand the general costs and benefits of a program and gross changes in process parameters, local conditions and practices by suppliers could shift the analysis significantly. It is recommended that King County conduct a pilot grease program at South Plant to develop the needed parameters for a robust analysis. Stress testing a digestion process at the pilot scale will better define program boundaries such as the ultimate size of the facilities, which could be driven by process limits or market availability. Most co-digestion facilities appear to show an economy of scale, after which the benefits more than pay for the costs. Understanding if King County will overcome that threshold is important. Careful analysis of the program conditions can identify that point and allow the County to assess the overall value of the program in an effective manner. This approach has been taken by other utilities in the region. Metro Vancouver (Vancouver, BC), is currently in the midst of a pilot testing regime to better understand the impacts of hauled liquid wastes on their Class A thermophilic digestion system and to better define the operations and maintenance costs, equipment effectiveness, and potential for carbon emissions reductions. As part of their strategic approach, the pilot facility can also serve as a sludge receiving station for materials from their 4 other plants.

Based on the findings of this memorandum it is recommended that King County proceed forward with a pilot scale facility to better understand the boundary conditions of FOG co-digestion at South Plant. It is recommended that the facility be designed such that it serves several operating roles for the plant, such as sludge receiving, and be designed to be incrementally expanded such that the facility becomes part of a larger facility if the economic and environmental benefits prove out.

References

Bailey, R. " Anaerobic Digestion of Restaurant Grease Wastewater to Improve Methane Gas Production and Electrical Power Generation Potential" Proceedings of the Water Environment Federation Technical Exhibition and Conference, San Diego, CA, 2007.

Brown and Caldwell, "SRWTP Biogas Enhancement Pilot Test-Draft Report", Sacramento Municipal Utility District, California, July 15, 2009.

Brown and Caldwell, "Investigation of Co-digestion at the Tacoma Central Treatment Plant", City of Tacoma Environmental Services, May 2010

Davidsson, A. C. Lovstedt, J. la Cour Jansen, C. Gruvberger, H Aspegren " Co-digestion of Grease Trap Sludge and Sewage Sludge" Waste Management, 28, 2008., 986-992.

Ferguson, J, H. Gough.*"Co-digestion of Food Industry Wastes in a TPAD Digester Systems" Prepared for Brown and Caldwell and the City of Tacoma, August 5, 2009.*

Garza, O.A. (2004). "Food Service Establishment Wastewater Characterization and Management Practice Evaluation." Texas A&M. 2004.

Gerardi, M. H. *The Microbiology of Anaerobic Digesters*, Wiley-Interscience John Wiley & Sons Inc., Hoboken, New Jersey, 2003

Kabouris, J.C., U. Tezel, S.G. Palvostathis, M. Engelmann, A.C. Todd, R.A. Gillette. "*The Anaerobic Biodegradability of Municipal Sludge and Fat, Oil, and Grease at Mesophilic Conditions*" Water Environment Research, 80 (3), 2008.

Kemp, J.S., D. Egge, D. Zitomer. " Effect of Iron Addition on Thermophilic-Mesophilic Anaerobic Digestion" Proceedings of the Water Environment Federation Residuals and Biosolids Conference, 2008, Philadelphia, PA., April 2008.

King County (2011), Personal Communication: Rick Butler stated recent dye testing results during Project Kickoff Meeting, July, 28, 2011.

Muller, C.D., D. Dursun, R. Merlo, S. Krugel, A. Ekster, B. Yerrapotu. "Deriving More Information from Volatile Solids Data" Proceedings of the Water Environment Federation Residuals and Biosolids Conference, 2011, Sacramento, Calif., May 2011.

Parry, D., S. vandenburgh, M. Salerno, R. Finger "Co-digestion of Organic Waste" Proceedings of the Water Environment Federation Residuals and Biosolids Conference, 2008, Portland, OR, May 3-6, 2009.

Schafer, P, D. Trueblood, K. Fonda, C. Lekvin, "*Grease Processing for Renewable Energy, Profit, Sustainability, and Environmental Enhancement*" Water Environment Federation Residuals and Biosolids Conference, March 30, 2008.

Speece, R. *Anaerobic Biotechnology and Odor/Corrosion Control*, Archea Press, Nashville, Tennessee, 2008.

Suto, P, D.M.D. Gray (Gabb), E. Larsen, J. Hake, " Innovative Anaerobic Digestion Investigation o f Fats, Oils and Grease" Proceedings of the Residuals and Biosolids Management Conference 2006, Nashville, Tenn., 2006.

United States Census Bureau "State and County Quick Facts: King County Washington" Last Revision June 3, 2011, http://quickfacts.census.gov/qfd/states/53/53033.html, August 10, 2011.

Wan, C., Q. Zhou, G. Fu, Y. Li, " Semi-continuous Anaerobic Co-digestion of Thickened Waste Activated Sludge and Fat, Oils and Grease" Waste Management (31) 2011.

Wiltsee, G.A. "Urban Waste grease Resource Assessment", National Renewable Energy Laboratory, November 1998.

Zengkai, Liu, "Anaerobic Co-idgesiton of Municpal Wastewater Sludge and Restaurant Grease" Masters Thesis, Uinveristy of Alberta, Edmonton, Alberta, 2011.

Attachment B: Facility Layout Technical Memorandum

701 Pike Street, Suite 1200
Seattle, Washington 98101
Tel: 206-624-0100
Fax: 206-749-2200

Technical Memorandum

Prepared for: John Smyth, King County Project Manager

Project Title: Grease to Energy at South Treatment Plant

Project No.: 141326-002

Technical Memorandum 2

Subject: Business Case Evaluation for Conceptual Grease Facility at South Plant

Date: December 21, 2011

To: John Smyth, King County, Project Manager

Rick Butler, King County, Operations

Curtis Steinke, King County, Operations

From: Christopher D. Muller Ph.D., P.E., Brown and Caldwell, Project Engineer

Copy to: Ian McKelvey, Brown and Caldwell, Project Manager

Prepared by: ______________________________

Christopher D. Muller Ph.D., P.E., Senior Engineer, Washington: 47853, 8/1/2013

Ian McKelvey PE, Engineer III

Matthew Winkler, EIT, Engineer II

Reviewed by: ______________________________

Tracy Stigers, Vice President, Western Business Unit Wastewater Practice Leader

Table of Contents

List of Tables

List of Figures

1. Introduction

This Technical Memorandum No. 2 (TM-2) presents the findings of the business case evaluation (BCE) of co-digestion of fats, oils, and grease (FOG) at South Plant. The TM covers two primary sections: development of a preliminary receiving facility size based on the capacity of the digesters at South Plant and a BCE using a net present value (NPV) approach to define the facility's economic viability.

2. Brown Grease Receiving Facility

As reported in TM-1, King County's South Plant has available digester capacity and capacity to utilize additional biogas generated from a co-digestion program. Based on the limitations set forth in TM-1, the primary element that the County requires is a facility to receive the brown grease and process it to a feedstock that can be accepted by the digesters without negatively impacting plant operations and biosolids management. The following subsection describes the preliminary elements of the co-digestion receiving facility.

2.1 Grease Receiving Facility Capacity Definition

TM-1 described the capacity of the digestion system to accept brown grease as a supplemental feedstock for co-digestion in the South Plant digesters. The results of the analysis indicated that the primary limitations for grease receiving were:

- **Volatile solids loading rate of FOG**: The available organic loading capacity is sufficient to accept the target maximum fraction of volatile solids as FOG to the digesters, 30 percent of the average daily sludge volatile solids load, without exceeding the overall organic loading limit of the digesters, 180 pounds volatile solids per 1,000 cubic feet per day (lb-VS/1,000 ft^3-day). The average annual conditions with one unit out of service were found in TM-1 to be the limiting condition.
- **Hydraulic loading of FOG**: The hydraulic load of FOG is a function of the concentration of grease being received at the facility. It was reported in TM-1 that the hydraulic load could be highly variable with solids concentrations of grease ranging from 1 to 15 percent solids or higher. The maximum allowable hydraulic load is limited to the minimum allowable digester hydraulic retention time (HRT) 20 days, per County practice. Given the uncertainty in the concentration of FOG, demonstration testing was recommended to define this parameter and the needed equipment to maintain at 20-day HRT in the digesters.

Given the potential variability in the hydraulic and organic loadings a combination of facilities construction phasing and assumptions were used to develop a preliminary cost estimate and facilities footprint. The project team agreed that the facility would be phased in nature, with a demonstration-scale facility being constructed first to test specific process, operational, and logistical assumptions. The data from the demonstration facility would be used to evaluate the potential expansion of the grease receiving facility to its optimum capacity at a future date (with the demonstration facility being integrated into the full facility). For the purpose of this evaluation it was assumed that the expanded facility would be sized to provide sufficient grease to the digesters to equal 30 percent of the average wastewater sludge volatile solids load.

Based on these operating conditions and the information presented in TM-1 the design criteria described in the following subsections were used to develop the demonstration facility.

2.1.1 Total System Solids Loading

The following total system solids loading design criteria were used to develop the demonstration facility:

- Maximum organic loading of FOG to digesters: 0.30 $lb\text{-}VS_{FOG}/lb\text{-}VS_{sludge}$ at the average annual solids loading rate

- Volatile solids load of brown grease: 40,000 pounds of volatile solids per day (lb-VS/day)
- Volatile fraction of brown grease: 0.85 pound of volatile solids per pound of total solids (lb-VS/lb-TS)
- Total solids load of brown grease: 47,000 pounds of total solids per day (lb-TS/day)

2.1.2 Total System Hydraulic Loading

The solids concentration of grease was selected to be 4.6 percent for this analysis. Information presented in TM-1 (see TM-1 Table 3-1) suggested that a value between 4 to 5 percent total solids concentration was representative of interceptor material, discounting dewatered or thickened products. However, based on prior work we are aware of a large regional grease hauler that thickens/dewaters interceptor grease prior to disposal, achieving solids concentrations greater than 15 percent. It is possible that thicker-than-average products could be received. It is recommended that in during the operation of the demonstration facility brown grease is characterized for physical and chemical characteristics.

The hydraulic loading capacity was limited to the condition in which one unit was out of service at average annual conditions while maintaining a hydraulic retention time of 20 days.

2.1.3 Demonstration System Process Capacity

The following demonstration system process capacity design criteria were used to develop the demonstration facility:

- Facility size: It was assumed that the demonstration facility would be sized to maximally load a single active digester at South Plant. This would provide one experimental digester and a minimum of one control, with two reserved for core business practices, along with the sludge storage tank (Digester 5).
- Demonstration facility brown grease volatile solids load: 10,000 lb-VS/day
- Demonstration facility brown grease total solids load: 11,800 lb-TS/day
- Demonstration facility hydraulic load: 31,000 gallons per day (gpd)

Along with the process capacity elements specific assumptions were made about the logistical capacity of the receiving facility. Part of a successful receiving program includes a cost-effective point of disposal for haulers, both in terms of tipping fees and reasonable hauler dwell time. For this analysis it was assumed that the receiving facility would support the following:

- Assumes 24-hour availability of receiving facility
- Maximum number of trucks processed in a peak hour condition: 15
- Average truck volume: 1,500 gallons
- Maximum truck discharge time: 20 minutes
- Parking, sampling, washdown, and exit time allowance: 5 minutes
- Number of redundant truck hookups: 1

The information presented above represents assumed values and should be verified with haulers during the demonstration facility operation, or prior to detailed design of the demonstration facility. The County should also discuss the potential for haulers to stagger drop-off periods to reduce peaking at the facility. This could potentially reduce the size of equipment, saving on initial capital costs. The demonstration facility was assumed to be one quarter of the full facility capacity, two receiving points and associated equipment, but would not have redundant service at initial construction.

2.2 Receiving Facility Location

Locating a grease receiving facility for co-digestion must consider several factors to help reduced capital and operations and maintenance (O&M) costs. These include:

- **Proximity to digesters:** Locating the receiving facility farther from the digestion process can increase pumping costs and O&M costs. As the temperature decreases, grease congeals and fouls pipelines. This results in either significant additional maintenance costs to clean lines, the need for heat tracing, hot sludge flushes, or other practices to reduce fouling. Further, all pipes conveying grease should be glass-lined or of a like material to further reduce the fouling potential.
- **Truck traffic patterns:** The receiving of grease or other hauled wastes will increase the number of trucks arriving at the facility. Locating the facility on the periphery of the plant will reduce interior truck traffic, reducing the risks of accidents and/or unauthorized access to other areas of the plant. Creating loops, pull-through areas, or other patterns to reduce the amount of backing by trucks can reduce congestion and traffic blockages on plant access roads.
- **Security:** Tracking who enters and exits the plant is important, as well as denying haulers access to other parts of the plant. Adding gates, card readers, security cameras, and other security devices may be required if a facility is constructed in an area that cannot be readily isolated.
- **Proximity to services:** The availability of services to all locations is important as the receiving facility will require odor control, water, hot water, power, drainage, and access to sludge lines (digested or raw). Locating a facility in a remote location may increase the capital costs of the facility and require additional equipment or upgrades to provide the needed services.

Figure 2-1 provides an aerial view of South Plant that shows the ideal area within which to locate a grease receiving facility and other potentially important infrastructure elements at South Plant.

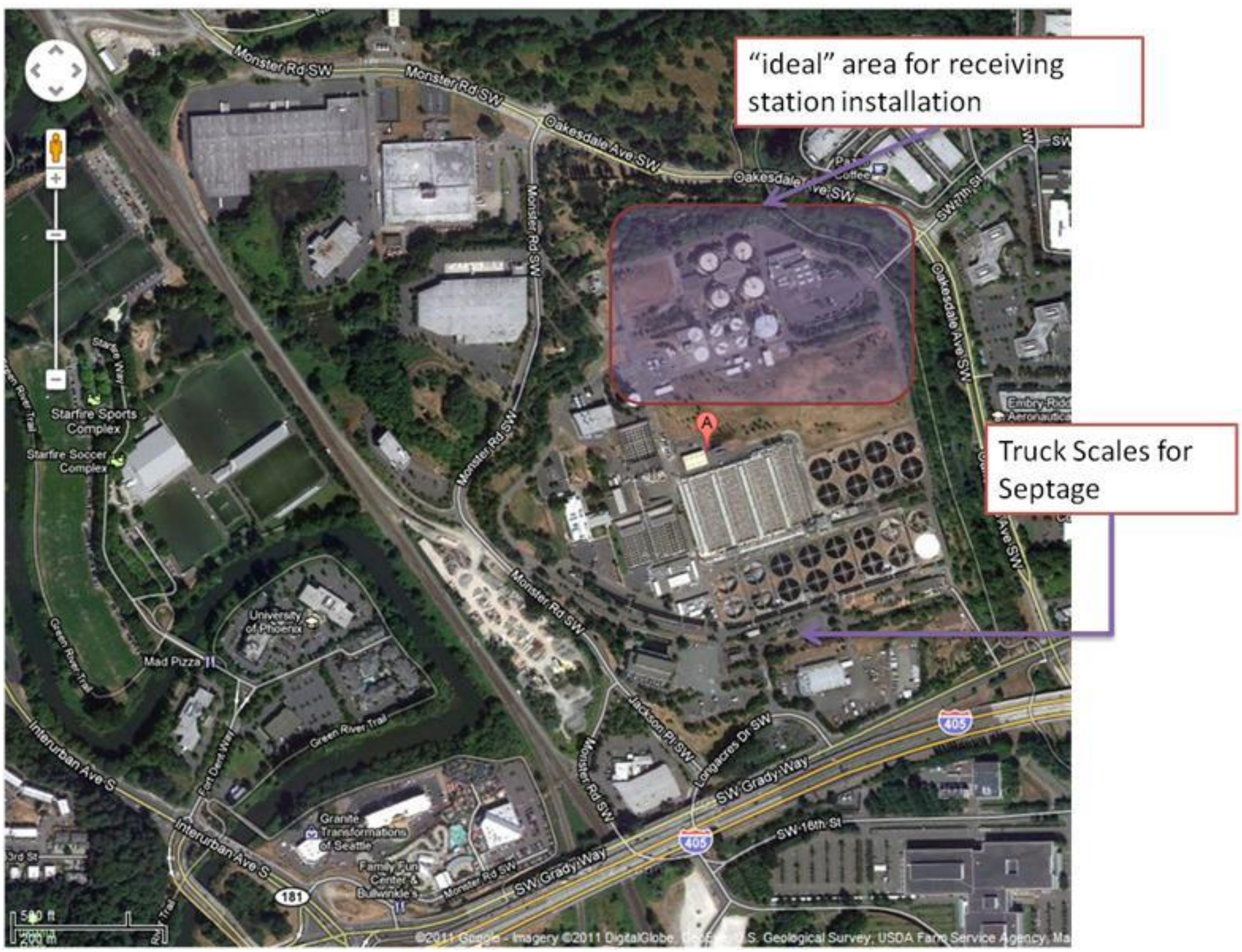


Figure 2-1. Aerial view of South Plant denoting critical areas for brown grease co-digestion

The preferred or recommended location for a grease receiving facility is near the solids treatment systems at South Plant, as that area meets many of the criteria noted above. The existing septage truck scales could potentially be used for grease haulers as they enter the plant or the County could assume that all trucks are full and charge a flat rate. Figure 2-2 shows several potential locations for a brown grease receiving facility around the solids treatment facilities. After evaluating the location of utilities, potential land uses, and truck access, the project team recommended that Site G in Figure 2-2 be used for a grease receiving facility.

Figure 2-2. Potential locations for a brown grease receiving facility at South Plant

The County indicated that access to raw sludge feed lines, power, and water (potable, C-2 and C-3), are available and penetration into the gallery is relatively simple in that area, as shown in Figure 2-3. Closer inspection of Site G indicated that no major structures would be impacted if tanks and equipment are maintained above grade, as shown in Figure 2-4. The County also indicated that the soils are engineered soils down to about 15 feet below grade.

King County staff also noted that under the access road just to the east of Site G is a gallery with access to the thickened sludge (THS) feed lines to digesters 1, 2, 3, and 4. Figure 2-5 shows a potential tie-in point for the grease to be fed to the digesters using the thickened sludge feed lines. Figure 2-4A in Appendix A calls out these tie-in points on the County's process and instrumentation diagram (P&ID). Given the potential for fouling due to the low-temperature raw sludge the project team decided to tie into the digested sludge recirculation lines, located in the digester equipment room, for the conceptual grease facility design and cost estimate. If raw sludge preheating is implemented prior to construction of the demonstration facility and/or full facility, the County may want to reassess using the thickened raw sludge feed lines.

Based on the location, availability of utilities, land availability, proximity to digestion system tie-in, and flaws noted for other sites by the County, Site G was selected as the site for a brown grease demonstration- and full-scale facility.

Figure 2-3. Potential utility tie-ins for a demonstration- or full-scale grease receiving facility at Site G

(a)

(b)

Figure 2-4. Site G to the east (a) and west (b)

(a)

(b)

Figure 2-5. Potential tie-in point for brown grease to the digestion system at South Plant, downstream of the THS (b) flow meters (a)

2.3 Receiving Facility Conceptual Design

The design of a robust and reliable grease receiving facility accounts for the mechanical challenges of handling grease and the regulatory impacts of grease receiving on the biosolids program. The following section describes the equipment recommended as part of this conceptual design as well as some of the operating regulatory conditions governing the process.

2.3.1 Operational and Regulatory Considerations of Grease Receiving in Washington State

The technical and operational challenges of grease receiving are common regardless of location; however, the regulatory constraints in Washington are unique, especially for wastewater utilities that land-apply their biosolids.

2.3.1.1 Washington State “Inerts Rule” WAC-173-308-205

Washington State recently implemented its “Inerts Rule” (Washington Administrative Code [WAC] 173-308-205), which requires utilities that will land-apply or give away biosolids to the public to screen all materials in the biosolids to 3/8-inch or less, by July 12, 2012. Because brown grease will be co-digested with the sewage sludge at South Plant, the grease or the resultant biosolids would need to be screened prior to distribution through the County’s beneficial use program. While grease is potentially a difficult material to screen, it is a smaller stream to handle and pre-screening prior to digestion would keep the associated debris and inerts out of the digesters, which could reduce long-term maintenance on the digestion system.

2.3.1.2 Debris in Brown Grease

Brown and Caldwell has operated multiple demonstration facilities to look at the efficacy of brown grease co-digestion. A critical observation, further supporting the screening requirements, is the debris associated with the brown grease. Brown grease collected in interceptors is often contaminated with a variety of materials that go down the drain at food service establishments. The low-flow conditions and design of the interceptor to capture materials result in these contaminants being captured along with the grease. Figure 2-6 provides examples of the debris received from brown grease haulers at demonstration facilities.

(a) (b)

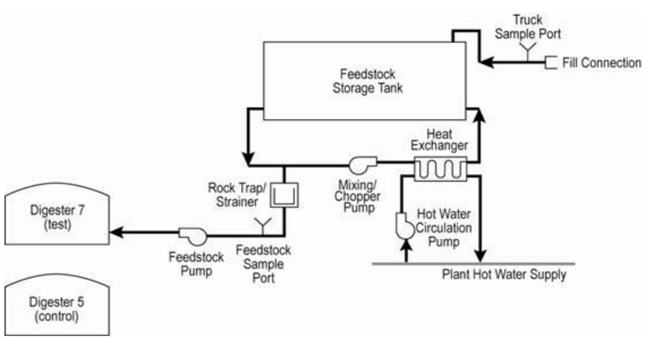
Figure 2-6. Examples of debris from brown grease haulers at FOG demonstration facilities at Tacoma Central Treatment Plant (a) and the Sacramento Regional WWTP (b)

The removal of debris from brown grease is a challenge that many utilities have not yet faced. As shown in Figure 2-7 the FOG receiving facilities at Riverside and Watsonville, California, do not have screening technologies. The demonstration facility operated at Sacramento Regional had screening, as shown in Figure 2-8, but became fouled with grease during operation—suggesting that basket strainers (un-insulated in this case) are not an effective mechanism for screening grease. The requirement by the Department of Ecology to remove manufactured inerts starting in July 2012 makes screening mandatory, and a demonstration facility would potentially allow for testing of different technologies.

(a)

(b)

Figure 2-7. Grease receiving facilities in Riverside (a) and Watsonville, California, which do not screen brown grease prior to co-digestion



(a)

(b)

Figure 2-8. Process flow schematic of Sacramento Regional WWTP FOG demonstration facility (a) and the fouling of the basket strainer screening system by grease (b)

2.3.1.3 Grit in Brown Grease

Grease interceptors collect manufactured inerts and grit as well. Grit in FOG can result in loss of storage capacity in tanks and/or premature wear on equipment. Figure 2-9, shows the wear experienced at the Sacramento Regional Wastewater Treatment Plant (WWTP) FOG demonstration study on a progressive cavity pump stator after 7 weeks of service.

Figure 2-9. Deterioration of a progressive cavity pump stator by grit at Sacramento Regional FOG demonstration facility

Although the source of the grit was the hauled grease, it is unknown if the grit was collected from interceptors or if it is contamination from haulers who collect other wastes as part of their business. Some smaller haulers co-collect or collect septage and other materials with the same truck. If the truck is not clean, then contamination can be carried over to the FOG. Interviewing haulers and demonstrating grease receiving can determine to what extent grit will be an issue.

2.3.1.4 Mixing

As discussed in TM-1 mixing is important to the overall performance and stability of the digestion system. The County's combination of gas mixing and pump mixing in its digesters produces results in a 95 percent active volume in the digester with approximately 5 percent dead volume. Due to its hydrophobic nature, grease naturally wants to separate from water. Mixing in the storage tanks will be critical as stratification can lead to inconsistent loading to the digesters and potential upset.

Figure 2-10 shows the stratification that was observed at the Sacramento Regional WWTP FOG demonstration project. It was thought that the Baker tank configuration was not ideal for mixing, resulting in sufficient dead space that allowed for stratification. Any potential facilities at King County would likely be permanent installations requiring a tank geometry that is more amenable to homogenizing the received grease.

(a)

(b)

Figure 2-10. Baker tank used for Sacramento regional temporary FOG demonstration facility (a) and the resultant FOG layer due to inadequate mixing (b)

For the conceptual facility a round tank with a cone bottom was assumed. The depth of cone and width-to-diameter ratio can be explored in detailed design. A taller round-tank configuration is thought to provide better mixing and reduce dead zones that can occur with rectangular shorter tanks.

2.3.1.5 Heating of Grease

Brown grease at ambient temperature tends to congeal and adhere to itself or solid surfaces. In piping systems this can lead to blockages. In process tankage it can form mats and grease balls, and lead to odors if not contained or cleaned. Heating grease liquefies it and reduces its adhesion to surfaces. Any holding tank for grease should be preheated to mesophilic temperatures to reduce fouling by the grease. Preheating is not viewed as an energy sink, beyond shell losses, as the grease will need to reach mesophilic temperatures for digestion.

Piping should be insulated and potentially heat-traced to reduce heat losses during conveyance. The Sacramento demonstration facility used insulation to reduce heat losses in piping, while the City of Tacoma did not require insulation, though the period of testing was much shorter and testing was not conducted in winter.

Hot water for washdown and sprays for screening processes should be available. While utilizing more energy hot water washing will required less effort than if cold water is used.

2.3.2 Conceptual Receiving Facility for Brown Grease at South Plant

Considering the factors outlined in the previous section a conceptual receiving facility design was developed for demonstration and build-out facilities. The recommendation for this receiving facility is to construct a demonstration facility that is expandable to full build-out capacity. TM-1 indicated that some process and materials handling questions, if addressed in a demonstration program, could lead to an improved definition of the scope of a full-scale grease receiving program and better definition of the benefits and costs of operating such a program.

Figure 2-11 shows a general process flow diagram representative of the conceptual grease receiving facility. The build-out facility would have an increased number of truck receiving points, screens, and a larger tank and pumps as well as the thickening unit based on the assumed total solids concentration. The demonstration facility would be smaller and may not contain the thickening unit. Figure 2-12 shows an alternative process configuration that could be used to reduce the number of screens and allow for the preheating of grease prior to screening. For the purposes of this analysis, the process flow diagram in Figure 2-11 was used as it was thought to be more conservative.

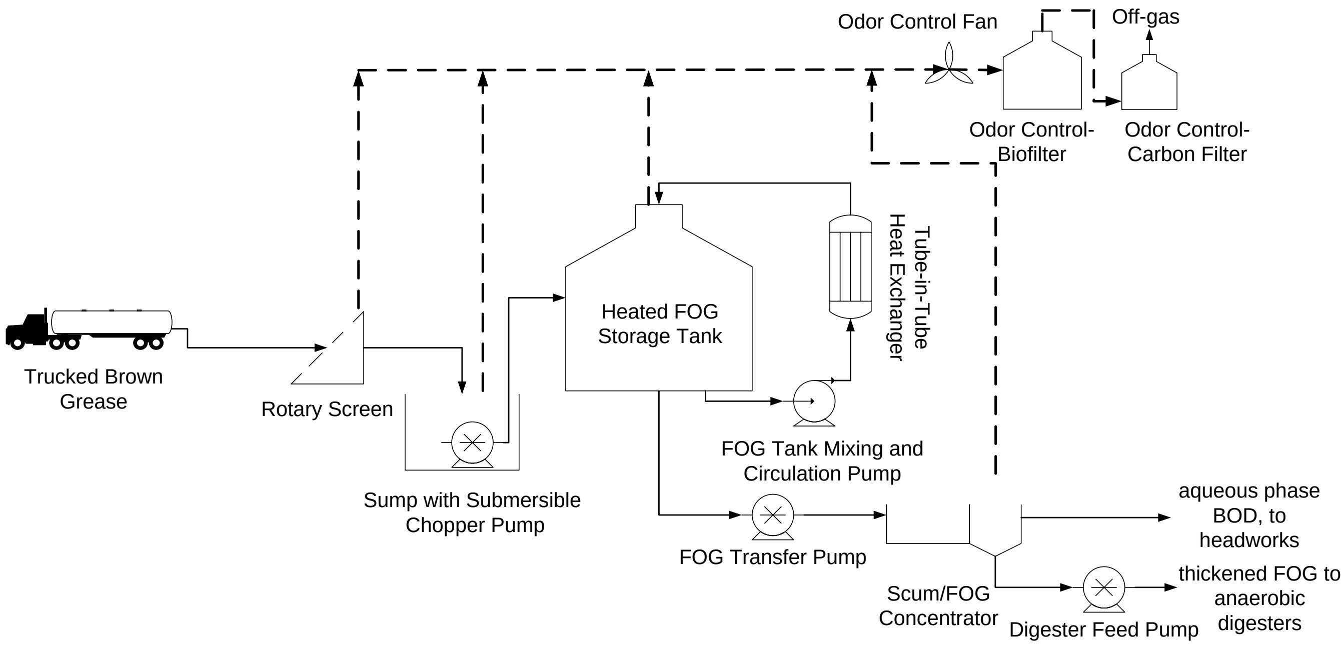


Figure 2-11. Basic process flow diagram of a South Plant brown grease receiving facility

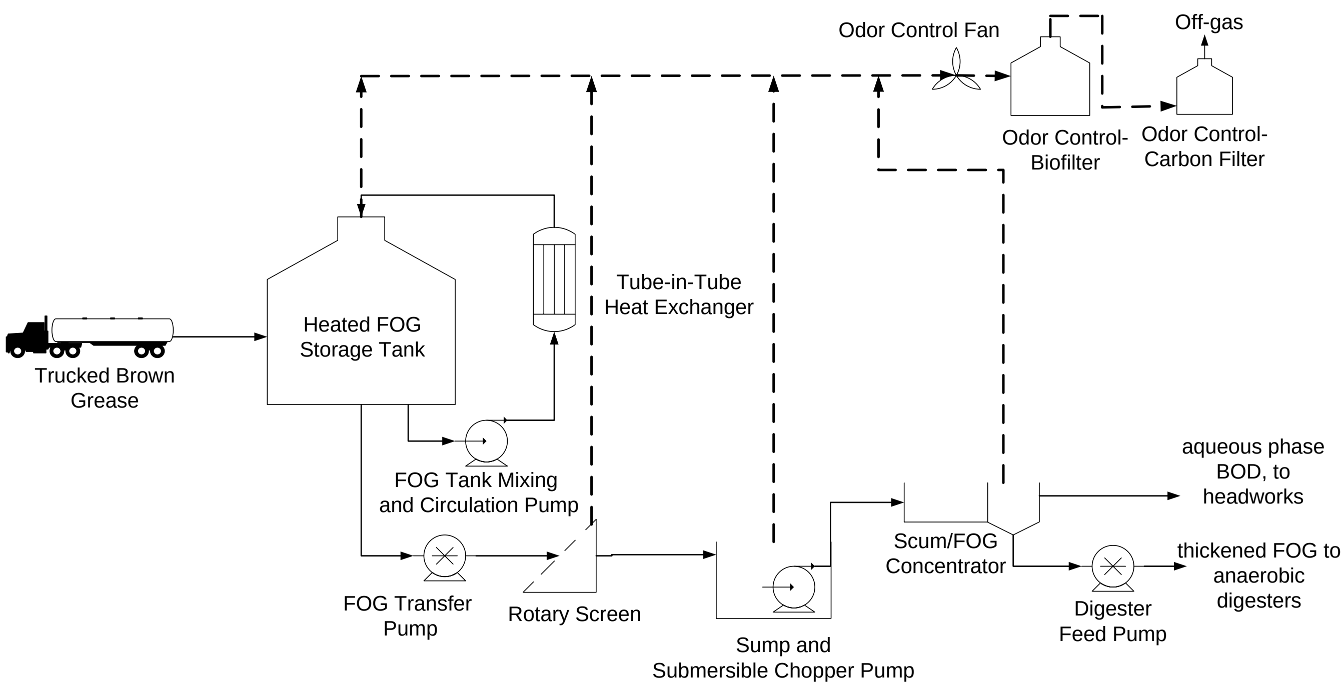


Figure 2-12. Alternative process flow diagram for brown grease receiving at South Plant

2.3.2.1 Sludge Screening Technology

The sludge screening technology selected for this conceptual design is a rotary screen designed for receiving liquid wastes from trucks. The representative technology is the IPEC TLT-200 screen. The IPEC TLT series screen is a closed system that removes debris from food wastes, FOG, and primary and secondary sludge. Figure 2-13 shows a photograph of the unit. The waste stream is pumped into the enclosed tank, where screening occurs. The screening mechanism consists of an auger fitted with brushes that sits in a perforated basket. The tank is fitted with spray nozzles that prevent bio-film and other growth from accumulating inside the tank. The spray water can also be heated to help prevent grease from solidifying. Debris larger than the perforated screen openings is continuously transported by an auger into the “pressing zone,” where the screenings are compacted into a plug. A second set of nozzles is located in the pressing zone to wash away loose solids. Liquid from the pressing zone is discharged through a short slotted screen section. The compacted screenings with a typical dryness of 40 percent or more are automatically expelled from the pressing zone. Of available IPEC units, the manufacturer recommends the TLT series for receiving facility service.

Figure 2-13. IPEC TLT trucked waste screen

Based on the conditions outlined in previous sections, Table 2-1 summarizes the capacity of each unit to be installed in the demonstration facility and the build-out facility.

Table 2-1. Capacity Data for Brown Grease Receiving Screens

Description	Value	Units	Notes/comments
Demonstration facility			
Number	1	each	
Design hydraulic capacity	150	gpm	Each screen
Rated capacity	200	gpm	
Build-out facility			
Number	4	each	3 duty, 1 standby
Design hydraulic capacity	150	gpm	Each screen
Rated capacity	200	gpm	

It is recommended that during detailed design a more thorough evaluation of screening technologies be conducted. Other manufacturers of similar products could provide a similar level of service or other technologies, which could be used to provide a clean product. In this case mechanical screening was selected as it meets the “Inerts Rule” definition. If the County wants to use other technologies it may need to apply for a variance from the State. Further, grease screening is not a common practice and there is little practical experience in the wastewater industry, as utilities who are co-digesting FOG are outside of the state of Washington and not subject to the same regulations. It is recommended that significant effort be placed into the selection of this equipment as it could become a process bottleneck if not well designed and/or incur significant operator attention.

2.3.2.2 Mixing and Transfer Pumps

The recommended FOG transfer and mixing pump is a chopper pump, which was selected based on its reported use at other FOG receiving facilities and its ability both to convey solids and to homogenize the FOG. Table 2-2 summarizes the capacities of the pumps used in this analysis.

Table 2-2. Capacity Data for Brown Grease Receiving Sump and Circulation Pumps

Description	Value	Units	Notes/comments
Demonstration facility			
Number of sump pump	1	Each	Convey screened grease to holding tank
Pump technology	Submersible chopper		
Design hydraulic capacity	300	Gpm	Added capacity for high rate discharge of 2 trucks with simultaneous discharge
Build-out facility			
Number of sump pump	1	Each	Convey screened grease to holding tank
Pump technology	Submersible chopper		
Design hydraulic capacity	900	gpm	Added capacity for high rate discharge of 6 trucks with simultaneous discharge

The County indicated that it would like to standardize equipment as much as possible to reduce the number of spare parts on hand, and reduce additional training. Chopper pumps are not standard equipment at South Plant and could be replaced with a combination pump-and-grinder assembly. However, that would double the number of equipment pieces, which could increase maintenance hours. This approach of inline grinders instead of grinder pumps has not been reported at other FOG facilities. It is recommended that the County conduct a BCE to determine the overall cost of ownership of the two models of operation during detailed design. A BCE can help the County select equipment that has the lowest cost of ownership, an analysis that is beyond the scope of this preliminary evaluation. Further, if the County wants to explore the efficacy of other pump/grinding approaches the demonstration facility could be designed to allow for modifications and demonstration of different technologies, such as the WEMCO Hydrostal screenings pump, as an example.

In this analysis it was assumed that redundant units were not required. During detailed design the need for redundancy could be further evaluated and verified during demonstration testing.

2.3.2.3 FOG Transfer and Digester Feed Pumps

Progressing cavity pumps were selected to convey the screened and heated grease to the digesters. Progressive cavity pumps have been successfully used to convey grease and are the technology the County uses to convey thickened sludges to the digesters. The County indicated that rotary-lobe pumps would not be acceptable, given past County experience with the technology. The capacity of the progressive cavity pumps are summarized in Table 2-3.

Redundant units were not supplied in this analysis; except for the build out digester feed pumps, as the County indicated that they stock spare parts for progressive cavity pumps. It is assumed that the County would have the spare parts needed to service the new pumps. During detailed design it is recommended that, when possible, the pump selection process standardize on pumps the County already owns to reduce the spare parts inventory and training required to service them.

Table 2-3. Capacity Data for Brown Grease Receiving Digester Feed Pumps			
Description	Value	Units	Notes/comments
Demonstration facility			
Number of pumps	1	each	Convey screened grease from holding tank to the digester, at build-out it will become a transfer pump to the concentrator
Pump technology	Progressive cavity		
Design hydraulic capacity	22	gpm	
Build-out facility			
Number of transfer pumps	1	each	Convey screened grease from holding tank to the concentrator
Pump technology	Progressive cavity		
Design hydraulic capacity	64	gpm	Added capacity for high rate discharge of 6 trucks with simultaneous discharge
Number of digester feed pumps	2	each	Convey screened, heated and thickened grease to anaerobic digesters
Pump technology	Progressive cavity		
Design hydraulic capacity	85	gpm	1 duty, 1 standby

2.3.2.4 FOG Storage Tank Construction

The storage tank for the screened brown grease was assumed to be concrete for this analysis. Other materials may be acceptable and could reduce construction costs. Concrete was selected as it was thought to provide a more conservative initial capital cost. During detailed design it is recommended that the County investigate the cost of ownership between different materials of construction for the FOG storage tank. Table 2-4 provides information regarding the proposed storage tanks for the demonstration and build-out facilities.

Table 2-4. Capacity Data for Brown Grease Receiving Digester Feed Pumps			
Description	Value	Units	Notes/comments
Demonstration facility			
Tank diameter	17	feet	
Side water depth	18	feet	
Freeboard	3	feet	Added buffer capacity for hydraulic loading
Total volume	31,000	gallons	
Build-out facility			
Tank diameter	24	feet	
Side water depth	27	feet	
Freeboard	3	feet	Added buffer capacity for hydraulic loading
Total volume	92,000	gallons	

The grease storage tank should be lined to reduce grease adhesion to the walls as well as protect the surfaces from the corrosive environment, and for odor control.

2.3.2.5 Grease Heating

If ambient temperatures are low enough, brown grease congeals and adheres to and fouls surfaces. To prevent this, a combination of hot water usage, process heating, and insulation was recommended for the conceptual facility design. Wash water for spray bars in the screens and at utility stations will be provided to keep grease in a soluble form or readily remove grease adhering to surfaces, such as the sump walls.

The grease held in the storage tank will be heated using a tube-in-tube heat exchanger to raise the grease from ambient temperatures to mesophilic temperatures (95–100 degrees Fahrenheit [°F]). This will serve not only to preheat the grease prior to digestion, but also to liquefy the grease reducing its buildup on the tank interior and downstream piping.

Heat exchangers were selected as the heating technology as there is a ready supply of hot water in the South Plant's hot water system. Alternative heating technologies could be used, such as steam or electric resistance heating. Given the successful use of tube-in-tube heat exchangers at the Sacramento regional demonstration facility and heat exchangers take advantage of available heat energy at South Plant in the hot water system.

2.3.2.6 Grease Thickening

Based on the analysis presented in TM-1 the digestion process is hydraulically limited when FOG concentrations are on the thinner end of the range. To mitigate the hydraulic impact on the digestion process a scum thickener was included, as shown in Figure 2-1. According to the vendor representative the scum concentrator works with trucked grease, based on a recent demonstration study. The vendor states that the process historically achieves a concentrated scum product of 30 to 50 percent solids. In this analysis it was assumed that the brown grease would be thickened to 30 percent, the low end of the range. The vendor also reported that the scum concentrator in the demonstration collected heavier material in the flow tank, such as large food particles, which would need to be removed periodically. For this analysis we assumed that the scum concentrator would be installed with the build-out facility and not initially with the demonstration facility, as it is not yet known whether it is needed. This decision may need to be revisited in detailed design, if the County wants to test the concentrator and/or other technologies, but space on the demonstration should be allocated for its potential installation during demonstration testing.

Figure 2-14. Scum concentrator for grease thickening

(source: Envirocare Web site)

2.3.2.7 Process Piping

All process piping is assumed to be glass-lined, which will reduce the adhesion of the grease and the long-term maintenance costs of cleaning and clearing of blockages.

2.3.2.8 Odor Control

Odor control will be required at the grease receiving facility as significant foul odors have been reported when it is not practiced. An odor control system was sized to handle the foul air for the build-out condition, treating the air from the storage tanks, sumps, and screening processes. It was assumed that the storage tanks would require 0.5 standard cubic feet per minute per square foot (scfm/ft^2) of tank surface and the sumps and screens would be under a negative pressure of -0.05 inches of water column. The facility would need to treat approximately 800 standard cubic feet per minute (scfm) based on initial sizing estimates. For the purposes of this analysis it was assumed that the demonstration facility would house the same unit that would serve the build out facility, and still be effective. A more detailed analysis of the odor control options for the demonstration facility should be conducted during detailed design.

The County initially suggested that carbon be used as the sole odor control technology, increasing the amount of carbon in the treatment system as the receiving facility expanded. Brown and Caldwell is in the process of installing an odor control system at a large wastewater plant practicing co-digestion. That facility will be using a combination of a bioscrubber followed by a carbon polish step to treat the foul air. Based on our understanding of the odorants from co-digestion facilities and the capability of different processes to remove them, the dual process approach (bioscrubber and carbon polish) was recommended over the carbon only approach.

Because of the potential for high moisture-content air fouling the carbon system if moisture removal fails—whether polishing or a standalone carbon-only system—the odor control system should receive additional research and testing during demonstration. In detailed design the efficacy of other technologies (e.g., caustic-carbon followed by carbon) should be evaluated including approaches to receiving station odor control take by other utilities.

2.3.3 Facility Layout and Cost

Using the equipment described above and the process flow diagram presented in Figure 2-11 the following facility layout represents the conceptual FOG receiving facility for South Plant. Based on the County direction that if the program were successful at the demonstration scale the County would likely move to full implementation, a phased rather than modular approach to construction was used. The demonstration facility would represent approximately a quarter of the total system capacity for four anaerobic digesters, based on a 30 percent volatile solids loading fraction as FOG and assuming that hydraulic capacity limits will be met either by high raw grease solids concentrations or use of a thickening device. Figure 2-15 provides a basic layout of major equipment associated with the demonstration and full implementation of grease receiving at South Plant.

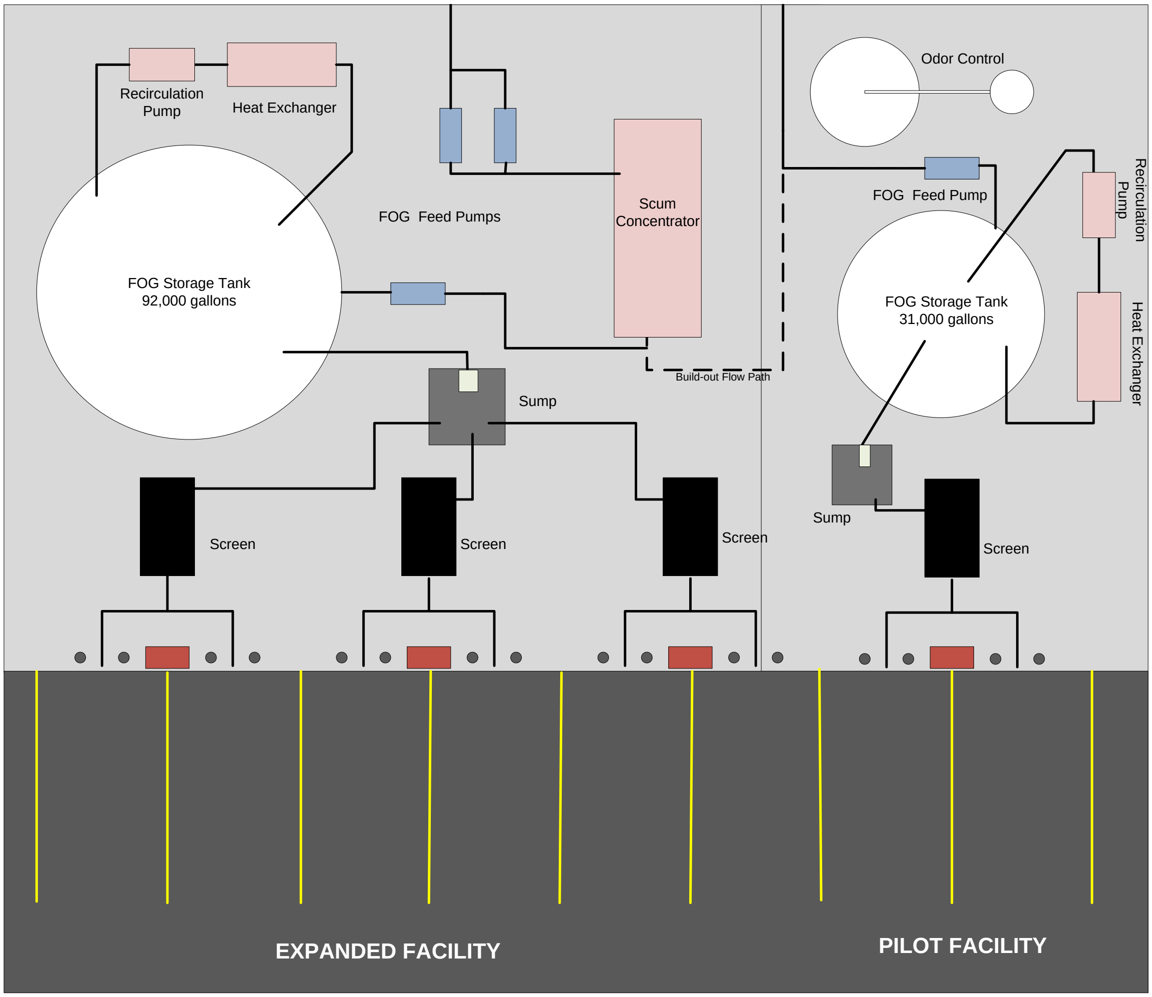


Figure 2-15. Conceptual grease receiving facility layout for South Plant

Access to the grease receiving facility could be obtained by entering the plant via 7th Street (see Figure 2-19 in Appendix A), which would not allow use of the existing truck scales. This would require the County to charge on a full truck basis rather than partial load, which weighing would allow. During a more detailed analysis an economic evaluation can be conducted to determine whether the weighing of trucks would provide a benefit to the County.

Assuming the grease receiving facility is installed at Site G, and using Figure 2-15 as a conceptual layout of the equipment, a footprint was developed along with a capital cost estimate. The conceptual facility at full build-out has an estimated footprint of 9,555 square feet (105 feet long by 91 feet wide). Based on initial estimates it appears that Site G will have sufficient space to accept the receiving facility. The facility would be constructed in two phases: the demonstration facility, which is estimated to cost approximately $985,000, and the expanded facility, costing an additional $2,191,000, based on the planning-level cost estimate provided in Appendix B.

3. Business Case Evaluation of Grease Receiving at South Plant

This section describes the business case evaluation (BCE) conducted to determine if utilizing excess digester capacity for grease digestion would make fiscal sense for King County. A 20-year NPV was used to determine the impact of costs and benefits realized in the analysis. The BCE process accounts for the costs and benefits realized under a given set of conditions. The analysis conducted assumed that King County would construct the facility described in Section 2 of this TM. The facility would start receiving maximum loading following construction in 2012 for a period of 20 years and the resulting biogas would all be sold to Puget Sound Energy (PSE) after making deductions for process heating. It was also assumed that all biogas was purified through the Binax system prior to use, sale, or process heating. The following subsections describe the parameters accounted for in this analysis and the ultimate NPV of the project.

3.1 Economic Parameters

Based on conversations with the County the following escalation rate and discount rate were assumed to evaluate the 20-year NPV.

- Escalation rate: 5 percent, based on County direction
- Discount rate: 3 percent, based on County direction

3.2 Biogas Production from Brown Grease

The facility was sized based on the condition described at the start of this TM. Based on those loading conditions and assuming a volatile solids destruction rate of 85 percent for brown grease and a biogas yield of 18 cubic feet of biogas per pound volatile solids destruction (ft^3-biogas/lb-VSd), the addition of grease would increase gross biogas production by 612,000 cubic feet of biogas per day (ft^3-biogas/day). The net gas production, removing the gas demand for grease preheating and accounting for BOD recycled back to the secondary system from the concentrator and losses from the Binax system, would be approximately 358,000 ft^3-biogas/day. The impact of grease addition on biogas composition has been variable in the literature; therefore, it was assumed that the biogas composition would be consistent with County historical data, approximately 60 percent methane and 39 percent carbon dioxide on a dry basis.

It should be noted that based on the information presented in TM-1 regarding the waste gas burners, the added biogas from a fully implemented facility will exceed the capacity of all three waste gas burners at a peak day condition, when evaluated using Brown and Caldwell design peaking factors. Under these peak conditions the facility would not be able to flare all the biogas generated in the event of an emergency. If only the demonstration facility were constructed capacity would be sufficient in the waste gas burners, using the same capacity criteria, until approximately 2026 or 2027.

Factors that could further impact flare capacity include biogas peaking from peak grease loading, which is undefined at this time, and the volatile solids destruction and gas yield assumed in this analysis. If a demonstration is conducted these parameters should be further defined. For this analysis the capital cost for a new waste gas burner was not included.

Based on this initial biogas estimate the other unit processes, cogeneration, and the biogas scrubbing system appear to have sufficient capacity. However it should be noted that there is limited equipment redundancy (e.g., capacity of the gas compressors is two small units and one large) and their reliability is decreasing with age.

3.3 Capital Costs

The BCE conducted assumed that all facilities would be constructed in 2012, both demonstration and full implementation. The capital cost for the facility described in Section 2 of this TM were based on a Class 4 cost estimate as defined by the Association for the Advancement of Cost Engineering International, which assumes a level of design from 1 to 15 percent and carries a level of accuracy of -30 percent to +50 percent. A Class 4 estimate is used in feasibility analyses. Initial vendor quotes were received for major equipment items. Electrical, I&C, and structural costs were derived as a percentage. Note that to address security concerns, a higher level of I&C costs were assumed.

Based on these conditions Table 3-1 summarizes the total capital costs of the facility in 2011 dollars and the estimated allied costs the County would incur for each phase of construction.

Table 3-1. Summary of Facilities Capital Costs

Description	Capital cost (2011-$)
Capital costs for grease receiving	
Demonstration receiving facility	986,000
Expansion to full build-out	2,191,000
Allied costs for grease receiving project	
Demonstration receiving facility	318,000
Expansion to full build-out	835,000

3.4 Operations and Maintenance Costs

Based on the process flow diagram provided in Figure 2-11, the following subsections discuss the O&M costs included in this analysis.

3.4.1 Labor Requirements

Accepting FOG at South Plant will require additional staffing to meet the maintenance, clerical, laboratory, and administrative needs of the facility. At the time of authoring available data are limited on the needs of these types of facilities, as there is a limited number with no clear industry design standards. Based on this uncertainty it was assumed that to operate, maintain, and administer the program and facility a total of 3,825 hours of labor would be required at a rate of $48.10 per hour. Based on 1,700 hour per year availability of a full-time employee the facility would require approximately 2.25 full-time employees. Based on these conditions the annual labor costs would be approximately $184,000.

3.4.2 Facility Power Demand

The power demand of the grease receiving facility was estimated based on the major pieces of process equipment associated with the facility. It was assumed that the screens and sump pumps operate long enough to process all the grease and convey it to the storage tank 365 days per year, with a 10 percent contingency added. All other equipment was assumed to be operating 24 hours per day, 365 days per year. The cost of electricity was evaluated at $0.065 per kilowatt-hour. Based on these assumptions an estimate of annual power demand was made and summarized in Table 3-2.

Table 3-2. Summary of Electrical Power Demand for the Brown Grease Receiving Facility				
Description	Estimated horsepower (hp)	Estimated daily hours of operation (hr)	Number of units each	Annual electricity cost at $0.065/kWh ($/year)
Demonstration facility equipment list				
Tube-in-tube heat exchanger	n/a	n/a	n/a	
Hot water circulation pump	5	24	1	2,123
Submersible chopper pump	7.5	4.7	1	628
Recirculation chopper pump	7.5	24	1	3,185
FOG feed pump	5	24	1	2,123
Odor control unit	75	24	1	31,845
Trucked waste screen	1	4.7	1	84
Build-out facility				
Scum concentrator	12.1	24	1	5,125
Hot water circulation pump	5	24	1	2,123
Tube-in-tube heat exchanger	n/a	n/a	n/a	n/a
Submersible chopper pump	25	24	1	10,615
Recirculation chopper pump	25	24	1	10,615
FOG feed pump	10	24	1	4,246
FOG transfer pump	7.5	24	1	3,185
Trucked waste screen	1	4.6	3	246
Total annual electricity cost				76,143

3.4.3 Odor Control Media Maintenance

The odor control unit selected for this analysis includes an activated carbon unit, which must be periodically replaced. Based on vendor information a replacement frequency of 2 years was used at a cost of $2,260 for new media. It was assumed that labor would be covered under the labor costs for the facility.

3.4.4 Equipment Replacement

Receiving of brown grease will introduce wear on the equipment that can be reduced through preventive and routine maintenance. However, it is assumed that over the course of the analysis all of the process equipment will need to be completely replaced or undergo a major overhaul after 10 years of operation. Table 3-3 summarizes the pieces of equipment and the associated costs for replacement used in this analysis.

Table 3-3. Estimated Replacement Process Equipment after 10 Years of Service			
Description	Number	Unit cost (2011-$)	Equipment replacement cost (2011-$)
Demonstration facility equipment			
Tube-in-tube heat exchanger	1	20,000	20,000
Hot water circulation pump	1	3,925	3,925
Submersible chopper pump	1	8,550	8,550
Recirculation chopper pump	1	6,500	6,500
FOG feed pump	1	11,800	11,800
Odor control unit	1	65,000	65,000
Trucked waste screen	1	45,000	45,000
Build-out facility			
Scum concentrator	1	260,000	260,000
Hot water circulation pump	1	3,925	3,925
Tube-in-tube heat exchanger	1	35,000	35,000
Submersible chopper pump	1	8,550	8,550
Recirculation chopper pump	1	9,700	9,700
FOG feed pump	2	14,900	29,800
FOG transfer pump	1	14,900	14,900
Trucked waste screen	4	45,000	180,000

It should be noted that the tube-in-tube heat exchangers are assumed to not need replacing due to an assumed low wear potential.

3.4.5 Biogas Treatment Costs

The additional biogas generated from the co-digestion of brown grease would need to be purified to pipeline quality by the Binax system prior to sale to PSE. The County provided the following rates to estimate the cost of biogas treatment:

- Power costs for biogas treatment: $0.14 per therm produced
- Parts and maintenance: $0.06 per therm produced
- Labor costs: $0.02 per therm produced

Based on the above rates and an average biogas production rate of 750,075 therms per year from the additional brown grease digested, the following biogas treatment costs are incurred annually:

- Power costs for biogas treatment: $105,000
- Parts and maintenance: $45,000
- Labor costs: $15,000

3.4.6 Recycled Aqueous-Phase Biochemical Oxygen Demand Treatment Costs

The hydraulic limitations of the digestion system described in TM-1 will likely require that the received brown grease be thickened prior to digestion so the hydraulic retention time remains sufficiently high for continued stable digestion operations and biosolids product stability. A scum concentrator was selected as the technology to increase the solids concentration of the grease prior to digestion. A thickened grease product of 30 percent total solids was used to define the volume of flow returned to the head of the plant. The vendor contacted reported average thickened scum concentrations of 30 to 50 percent, thus the low range concentration was selected. It was also assumed that any settled solids returned in the underflow would be captured in the primary clarifiers without reduction in biogas potential, and the solids would be returned to the digesters with the thickened raw sludge. However, no net benefit for the conversion and ultimate digestion of biomass generated from the biochemical oxygen demand (BOD) recycled was taken.

Currently no data are available directly measuring the BOD concentration in the aqueous phase of the brown grease to be received by King County. To account for the BOD load a BOD concentration in the aqueous phase of hauled grease of 22,000 milligrams BOD per liter (mg-BOD/L) was assumed based on the work by Suto et al. (2006), for gravity-settled trucked brown grease. If a demonstration is conducted it is recommended that the County characterize the grease received to validate this value. Further it should be noted that some operational strategies could be used to reduce the return flow to the liquid stream treatment process, such as operating the thickener only during peak loading conditions and when a digester is out of service. This would reduce the BOD load and recover the energy content of that BOD as methane in the digesters. These operational refinements can be made during detailed design.

Based on these conditions it was estimated that thickening the grease, assuming the returned BOD represents the efficiency of the thickener as well, would add approximately 18,300 pounds BOD (lb-BOD) to the plant's influent. Assuming a cost of treatment of $0.10 per lb-BOD, based on an estimate by Brown and Caldwell's Jack Warburton, the County would spend approximately $686,700 annually treating recycled BOD.

3.4.7 Biosolids Production

Based on the process parameters assumed for this analysis the added grease will result in an increase in biosolids production, assuming that no synergistic effects are observed. Based on an 85 percent volatile solids destruction and volatile fraction of grease and a 40,000 pound per day volatile solids load of grease, the County could see an increase in biosolids production of approximately 13,000 dry pounds per day. Assuming that dewatering performance does not change and an average of 22 percent cake solids is observed, the daily biosolids from brown grease, hauled off for beneficial use, would be approximately 10,800 wet tons per day. The County estimated the average cost of disposal of biosolids, hauling, and application, to be $46 per wet ton, resulting in an additional disposal cost of $498,000 per year.

Along with hauling additional cost would be incurred due to added polymer demand. Assuming that biosolids generated from the digestion of brown grease exhibit similar dewatering properties as digested sewage sludge the added polymer costs to dewater the grease associated biosolids would be approximately $229,000 per year. This is based on a polymer demand of 38 pounds active polymer per dry ton, a polymer activity of 42 percent, and a price of polymer of $1.05 per pound.

It should be noted that this analysis did not include additional dewatering time or benefits from improved digestion through synergistic effects.

3.5 Revenues from Brown Grease Co-Digestion

The receiving and processing of brown grease at South Plant will incur capital and operating costs but also provide benefits, through revenues from tipping fees, the sale of gas to PSE, and the nitrogen contained in the additional biosolids. The following subsections describe these benefits and their impact on the BCE.

3.5.1 Gas Sale to Puget Sound Energy

The additional biogas generated from the co-digestion of brown grease will increase the revenues generated from the sale of the cleaned-up gas to PSE. Currently the County receives $0.55914 per therm introduced to the pipeline. Assuming that the net biogas produced is all introduced to the pipeline, the County could potentially received $419,400 per year from biogas sale.

Further increasing biogas production from co-digestion will likely further reduce carbon emissions, as biogas is a renewable energy source and it is displacing natural gas, a fossil fuel. It is recommended that in future analysis the County evaluate the carbon emissions (greenhouse gas emissions) impacts of a brown grease co-digestion program.

3.5.2 Tipping Fees from Brown Grease Acceptance

The acceptance of brown grease at South Plant should not be done for free; a tipping fee should be charged to help recover capital investments and cover operating costs. In this analysis the concentration of grease was sufficiently low to make tipping fees a significant factor in the analysis. Assuming that the County is able to receive the full quantity of grease at its facility the County could realize approximately $2,239,000 annually in fees if it charges at a rate of $0.05 per gallon.

Table 3-4 provides tipping fees reported by other utilities or haulers. The data suggest that the selected tipping fee is within the range of reason. It should be noted that it is approximately half the current rate charged for septage disposal at South Plant. Many smaller haulers collect both grease and septage. It is recommended that the County investigate where local haulers are disposing their grease and at what rates. This information could provide a more targeted rate selection that benefits both the County and local service providers.

Table 3-4. Tipping Fees Charged for Disposal of Different Waste Products

Agency	Brown grease tipping fee
Wastewater treatment plants: brown grease	
EBMUD	$0.11 per gallon non-concentrated $0.15 per gallon concentrated
Millbrae, Calif.	$0.14 per gallon + $25 per truckload
Oxnard, Calif.	$0.07 per gallon
Riverside, Calif.	$0.01 per gallon, (reported to be reduced to free due to competition)
SBSA, Calif.	$0.10 per gallon
Watsonville, Calif.	$0.04 per gallon
Metro Vancouver, B.C.	$0.25 per gallon (converted to USD at 1.05 CAD/USD)
Merlin, Ore.	$0.12–0.15 per gallon
Wastewater treatment plants: hauled sludges/septage	
Renton, Wash.	$0.102 per gallon, $200 per truck per year fee, $50 per truck set-up fee
Landfill rates charged or reported	
Darling Delaware	$28 per ton, (22 percent dewatered FOG)

3.5.3 Biosolids Nitrogen Revenue

Based on information provided by the County, for each wet ton of land-applied biosolids the end user pays a rate of $1.50 per wet ton for the organic in the biosolids nitrogen as a fertilizer surcharge. It was estimated that the County would collect approximately $16,250 annually from the surcharge.

3.6 Net Present Value Analysis: Full Utilization of Digester Capacity for FOG Organic Loading

Utilizing the information provided in the previous sections a 20-year NPV analysis was conducted for the full build-out facility (demonstration and facility expansion) as well as the demonstration facility alone to evaluate the impact of program scope on the NPV.

Assuming that King County were to construct a facility to utilize the maximum organic loading capacity for brown grease for a digestion system at South Plant the 20-year NPV was approximately $15.65 million based on a total construction cost of $4.33 million and operating costs summarized in the previous sections. Table 3-5 summarizes the capital and operating costs and annual revenues for the full build-out facility over a 20-year life cycle.

Table 3-5. Cost and Revenue Breakdown for Build-out Grease Receiving at South Plant

Description	Rate	Capital cost ($-million)	Total operating costs ($-million)	Total revenues ($-million)
Capital and allied costs				
Demonstration facility capital costs[a]		0.923		
Demonstration facility allied costs		0.318		
Build-out expansion costs[a]		2.440		
Build-out expansion allied costs		0.835		
Total capital and allied costs		4.52		
Operating costs				
Labor costs (admin and operations)	48.10 $/hr		7.96	
Power cost	0.065 $/kw-hr		2.69	
Carbon media replacement			0.037	
Biogas upgrading costs: FOG gas			5.83	
Treatment cost of recycled BOD	0.10 $/lb-BOD treated		24.28	
Biosolids disposal costs	39$/wet ton		14.94	
Dewatering polymer costs	1.05 $/lb polymer		8.10	
Total 20-year operating costs			63.84	
Revenues				
Biogas sale to PSE	$0.55914 per therm			14.86
Tipping fees	0.05 $/gal			79.14
Biosolids fertilizer surcharge	1.50 $/wet ton			0.57
Total 20-year revenues				94.57

[a] *Class 4 cost estimate per AACEI, carries a level of accuracy of -30% to +50%.*

Given that a market assessment was not conducted prior to this analysis there is the potential that the market may not support such a large facility; further, redundancy issues identified in the biogas scrubbing unit may reduce the reliable capacity of the system. The impact of reduced grease loadings to the NPV was investigated, assuming that the build-out facility was constructed as described in prior sections. Under these conditions it is assumed that either market or operational constraints limit the capacity of the system post-construction or tipping fees deviate from the assumed $0.05 per gallon assumed in the base BCE. Figure 3-1 summarizes the impact of reduced grease hauling and variable tipping fees on the NPV of a grease receiving facility at South Plant. What is apparent from the graph is that the facility would achieve a positive NPV at around 55,000 gallons per day, or about 45 percent of the maximum capacity of the system under the base condition. Lower grease loadings could be accepted if tipping fees were increased. The data suggest that further analysis of limitations to the system or program should be identified prior to construction, as the build-out capacity could be defined on parameters other than digester organic loading or hydraulic capacity and still provides the County a benefit. Further, the benefit could increase by better matching the facility capacity with factors that have yet to be completely vetted, such as the market or other limitations within the plant itself.

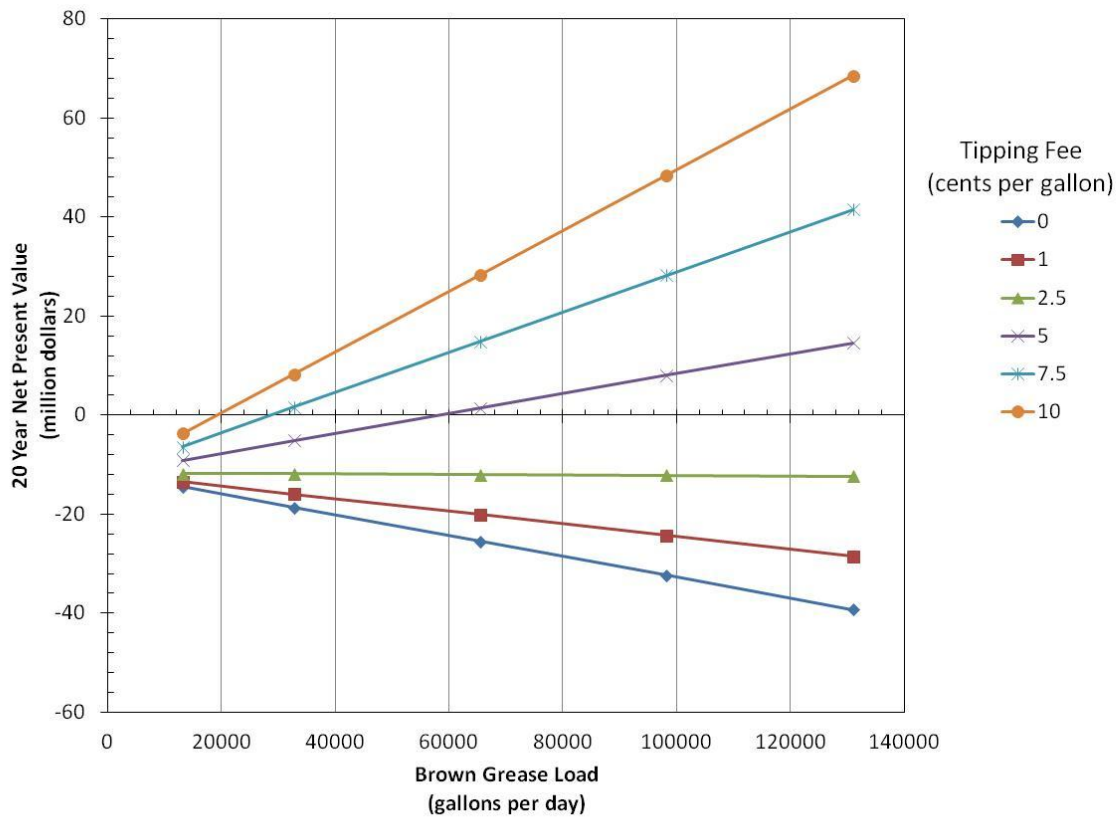


Figure 3-1. Impact of reduced grease acceptance on the 20 year NPV of a grease receiving facility at South Plant sized for build-out

It is recommended that the County further explore specific elements that could impact the overall viability of grease co-digestion at South Plant prior to construction of a build-out facility and in some cases the demonstration facility as well. These elements include:

- **Market assessment:** The grease receiving facility was sized based on a maximum organic loading rate to the digesters. No assessment has been conducted to determine the potential to collect that much grease and direct it to the plant. To collect the required grease for the facility South Plant would likely need most of the grease produced in King County. This assertion is based on an assumption of 2 million residents and an average per capita grease production rate of 13.37 lb-grease per person per year reported by Wiltsee (1998). Based on this value approximately 73,000 pounds of brown grease are produced per day in the county. This number includes grease from residences and business alike, with the former likely not being recoverable as it is traditionally sewered or placed in the solid waste stream. The County could reduce the size of the facility or look to supplement with other feedstocks, which could be identified through a market survey. The data suggest that if the County is able to capture significant quantities of highly degradable organics, with characteristics similar to those assumed here, a significant financial benefit could be realized.
- **Tipping fees:** Further refinement of the tipping fees charged for use of the facility may reduce the observed benefit from the facility or increase it if haulers are paying significantly more to dispose of materials at other locations. Preliminary evaluation of the sensitivity of the analysis to tipping fees is quite significant, especially with the assumed low solids concentration of the brown grease. As the energy content of the materials increases it is likely that the tipping fees will become less significant.
- **Average grease solids concentration:** The concentration of grease has an impact on the type and size of equipment selected, as well as the net energy production from the facility. During any demonstration testing it is recommended that the trucks be sampled and characterized for a variety of parameters, including solids concentration. This would provide a better estimate of the sizing of equipment.
- **Process parameters:** In this analysis it was assumed that the grease volatile solids destruction was approximately 85 percent and the biogas yield was 18 ft^3-biogas/lb-VSd. These estimates are based on literature values and assumptions. Improvements in either parameter can impact net energy production and biosolids disposal in potentially positive ways. It is recommended that the County further evaluate these parameters in a demonstration test.
- **Recycled BOD from scum concentrator:** The cost of treatment of the recycled BOD from the scum concentrator is significant. It represents not only a loss of revenue from energy but an expenditure of energy to convert that BOD to biomass for eventual digestion. It is recommended that the County characterize hauled brown grease to determine it characteristics and potential contributions of BOD to the liquid stream, if thickening is required. Further, the County may want to evaluate the potential of using different thickening technologies, such as dissolved air flotation (DAF) or fractionation, as they may provide better BOD recovery. During demonstration testing, if desired the County could investigate blending back thickening underflow with the concentrated grease to reduce the solids concentration going to the digester and reducing the BOD load back to the plant. However, based on the assumed solids concentrations and loading rates of the build-out facility will require some thickening to stay within digester hydraulic loading limits.
- **Nitrogen recycle to secondary treatment:** The additional organic load from brown grease to the digesters will result in an increase in the mass loading of nitrogen, typically in the form of ammonium, back to the secondary treatment process. If the County is required to meet a nitrogen limit in the future additional costs for aeration will be incurred and potentially cost for added carbon during denitrification. There are several options of handling these materials such as return to the secondary system or side stream treatment. It is recommended that the County explore potential treatment alternatives in the event that nitrogen limits are placed on South Plant in the future.

3.7 Net Present Value Analysis: Demonstration Facility Only Construction

The demonstration facility was based on the assumption that the County would want to stress the limits of digestion to understand how large of a brown grease program it could support or potentially a larger co-digestion program. Based on that assumption the facility was sized to allow for up to 30 percent of the volatile load as grease to the digesters at average annual conditions, for a single digester or one quarter of the potential maximum. This represents about 31,000 gpd of grease at 4.6 percent total solids and 10,000 lb-VS/day of volatile solids load. Because this facility is smaller, it could be operated with or without a scum concentrator, as the system can support 10 percent of the load as grease at 5 percent solids within the window of the analysis. This would assume that during demonstration testing the County would not take a digester out of service, a condition that would require the thickening of the brown grease to maintain hydraulic capacity. Based on the capacity analysis, in TM-1 it was noted that the plant could support the maximum organic load at 5 percent solids at average annual conditions with all units in service, likely sufficient for 4.6 percent solids. In the event that the facility is not expanded beyond the demonstration, even distribution of the grease at a flow of 31,000 gpd would be within the process limits for the planning horizon of this analysis. Based on this evaluation, the impact of BOD return load from thickening to the liquid stream can be eliminated as a cost to the program, both capital and operation.

Based on assumptions stated in this section and holding all other assumptions constant an NPV analysis was conducted for the demonstration facility as a standalone long-term facility for King County. Based on an initial capital investment of about $1.24 million (including County allied costs) the 20-year NPV was a positive $5.18 million—indicating that the project, even if stopped at this level, would be successful over the planning window.

Given that a market assessment has not been conducted a sensitivity analysis was conducted to determine the impact that both tipping fees and quantity of grease would have on the demonstration facility NPV. The boundary conditions for the tipping fees were set at free tipping and $0.10 per gallon, the septage receiving rate for South Plant. The boundary conditions for the quantity of grease received were set at the maximum capacity of the receiving facility (31,000 gpd) to 10 percent of the maximum capacity. Figure 3-2 presents the results of the sensitivity analysis for the demonstration facility.

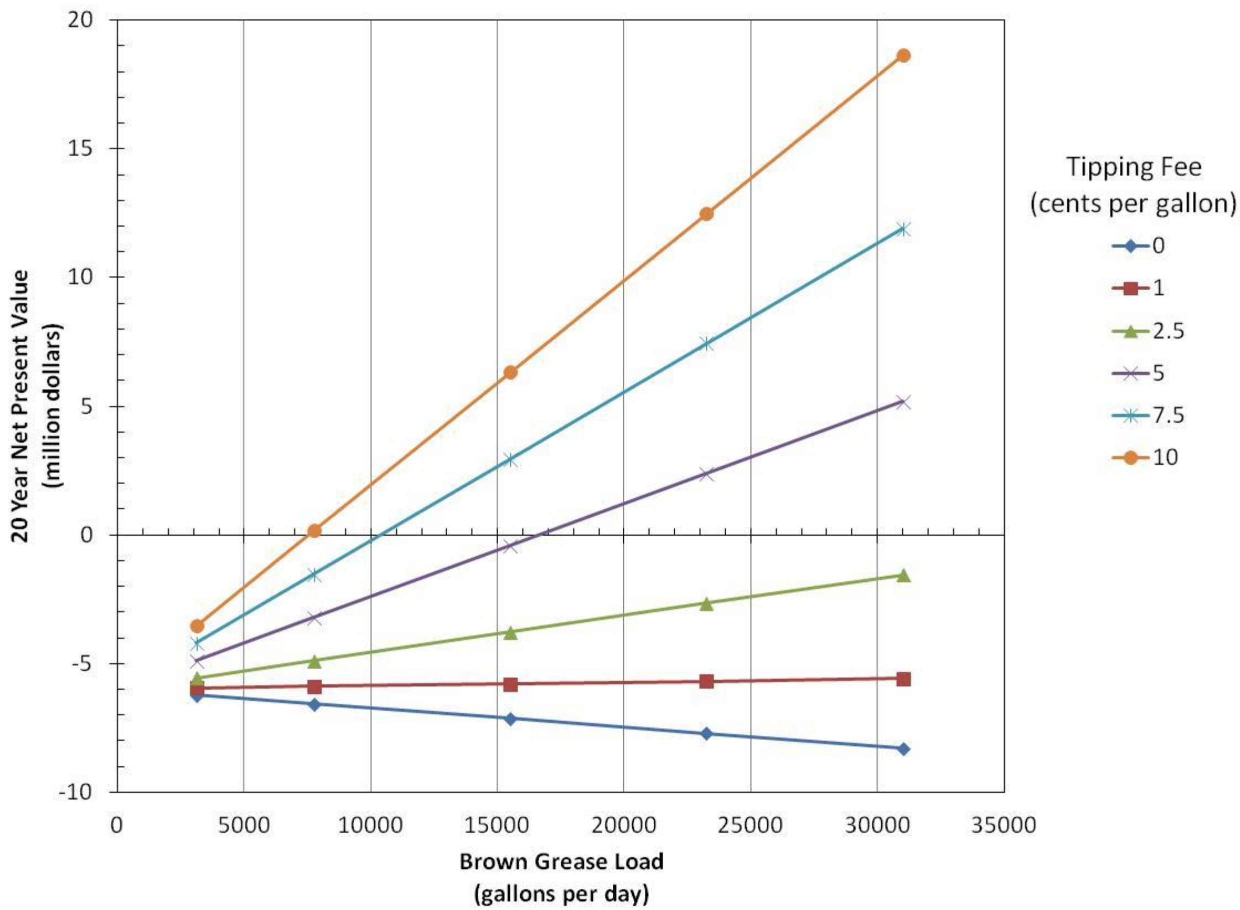


Figure 3-2. Sensitivity of demonstration facility NPV to tipping fees and volumetric grease loading

Based on the information presented in Figure 3-2 it appears that construction of the demonstration facility can maintain a positive NPV across a variety of loading and fee conditions. Given the potential flexibility of the demonstration facility to remain revenue-positive it is recommended that further analysis be conducted to refine operating and design assumptions for a full-scale facility, through the construction of a demonstration facility.

4. Recommendations

The 20-year NPV analysis for a facility to receive and co-digest the maximum organic loading rate for brown grease at South Plant was $15.65 million. The potential benefit to the County of constructing such a facility appears to be very positive; however, many assumptions need to be vetted in order to reduce the risk to the County of a stranded investment and/or unforeseen additional capital investments. To reduce these risks it is recommended that the County construct a demonstration facility to test the assumptions made in this analysis.

Concurrent with the demonstration program it is recommended that the County conduct a more detailed capacity assessment of the mechanical equipment associated with solids and biogas conveyance and processing. This study assumes that these processes have sufficient capacity to meet the added loads of a co-digestion program. By further evaluating these processes the County can assess any additional infrastructure needs to execute co-digestion and how those needs impact the overall economic viability of the program, as previously noted for the waste gas burners.

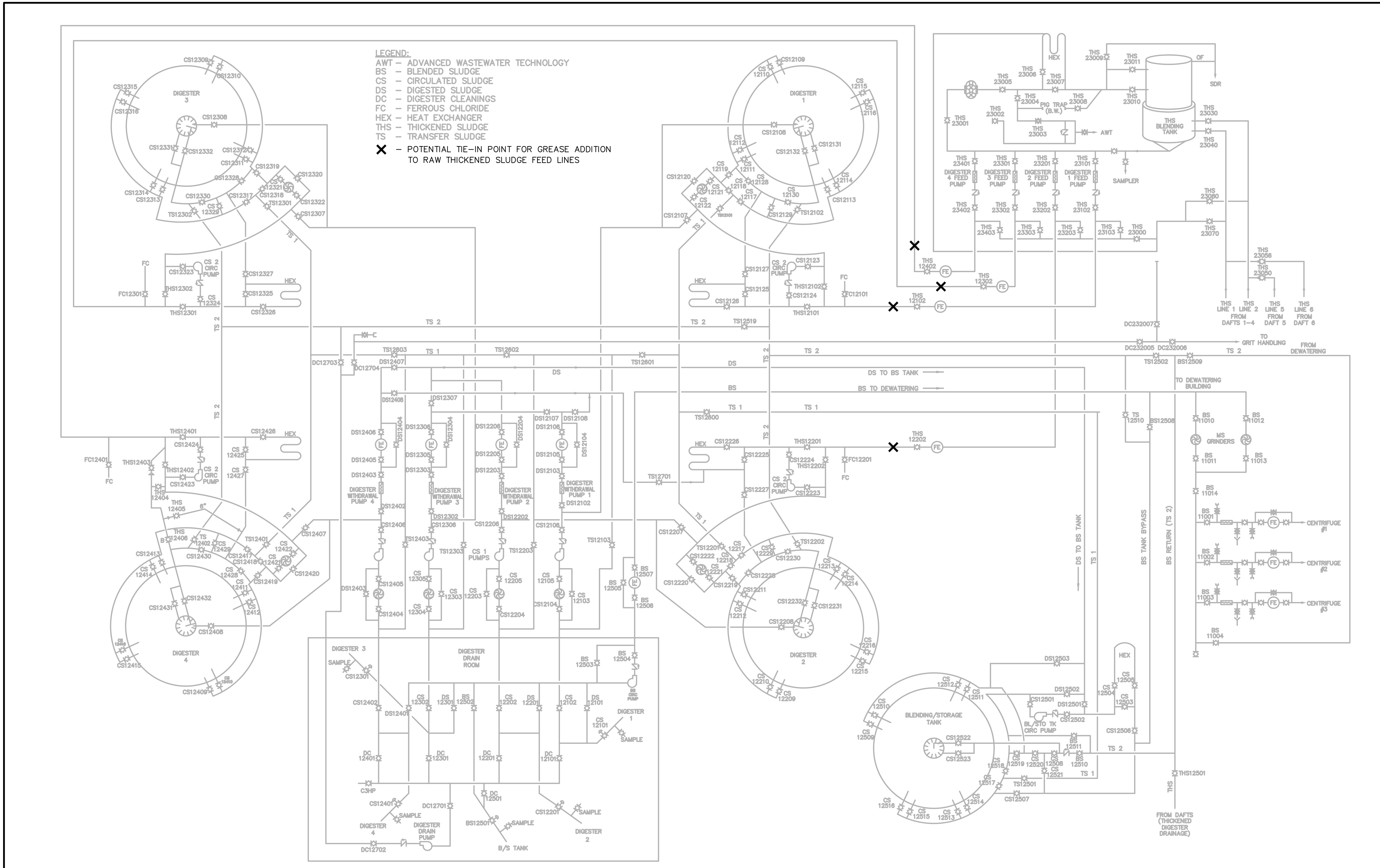
It is further recommended that the County evaluate the market availability of different supplemental feedstocks. Brown grease will likely be in significant quantities, especially if the County can attract large regional haulers. However, to realize the full build-out capacity it appears that additional feedstocks may be required. It is recommended that the market assessment first target other feedstocks that are compatible with a FOG receiving facility, to avoid additional equipment purchases. More difficult materials, such as source-separated food waste, should be considered last, while significant quantities would be available it would require additional infrastructure to process and collection and sorting programs would need to be developed with the local refuse hauler(s) to capture the material. Food waste should be evaluated if significant digestion capacity remains after other substrates are captured.

References

Suto, P, D.M.D. Gray (Gabb), E. Larsen, J. Hake, " Innovative Anaerobic Digestion Investigation o f Fats, Oils and Grease" Proceedings of the Residuals and Biosolids Management Conference 2006, Nashville, Tenn., 2006.

Wiltsee, G.A. “Urban Waste grease Resource Assessment”, National Renewable Energy Laboratory, November 1998.

Attachment A: Supplemental Figures



jmoffat
Nov 16, 2011 - 9:19am
P:\King County\141326 Mech-Elec On-Call_CAD\0-Project\Figures\Fig_2-4A.dwg

BROWN AND CALDWELL

Figure 2-4A

Digester Sludge Piping Diagram

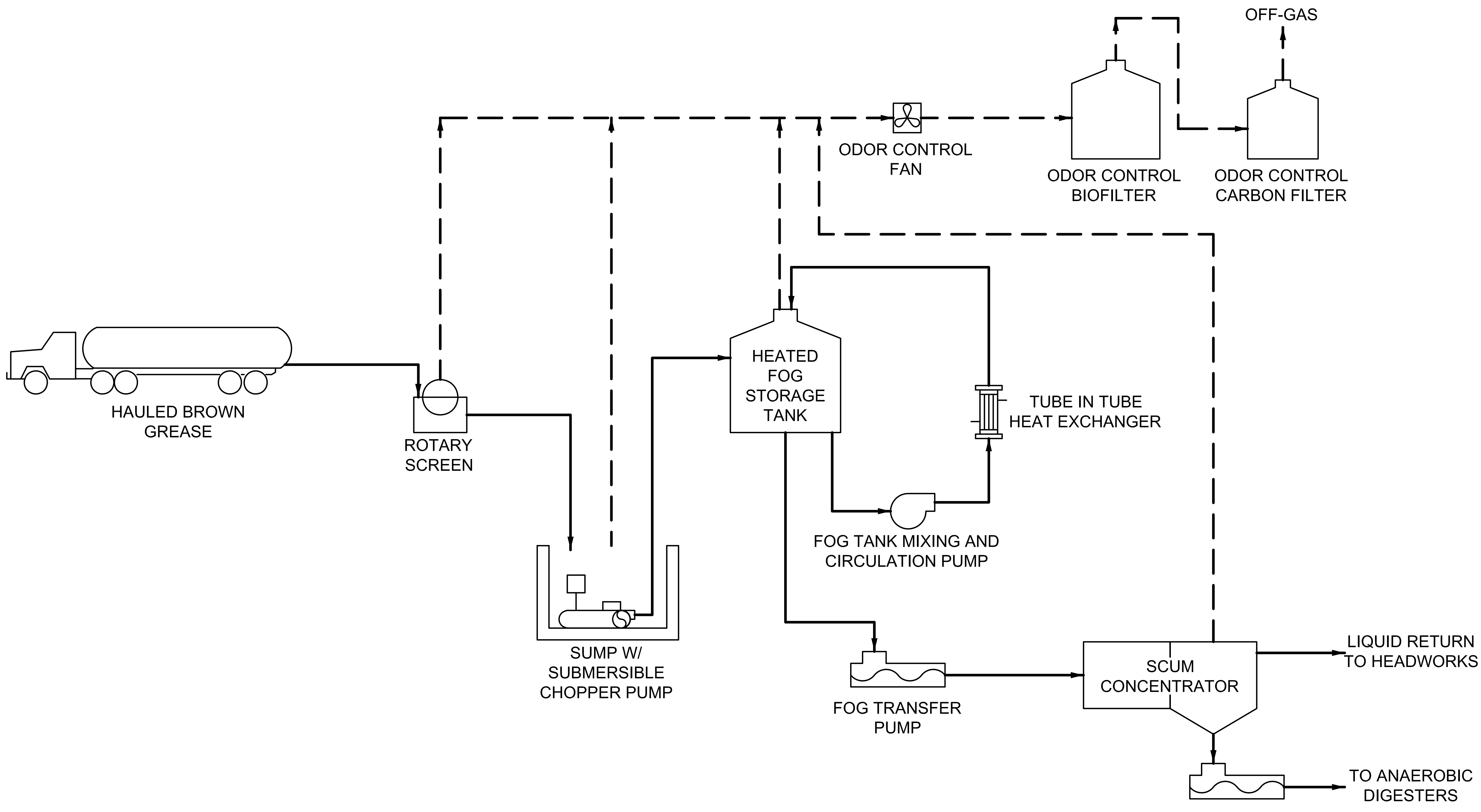
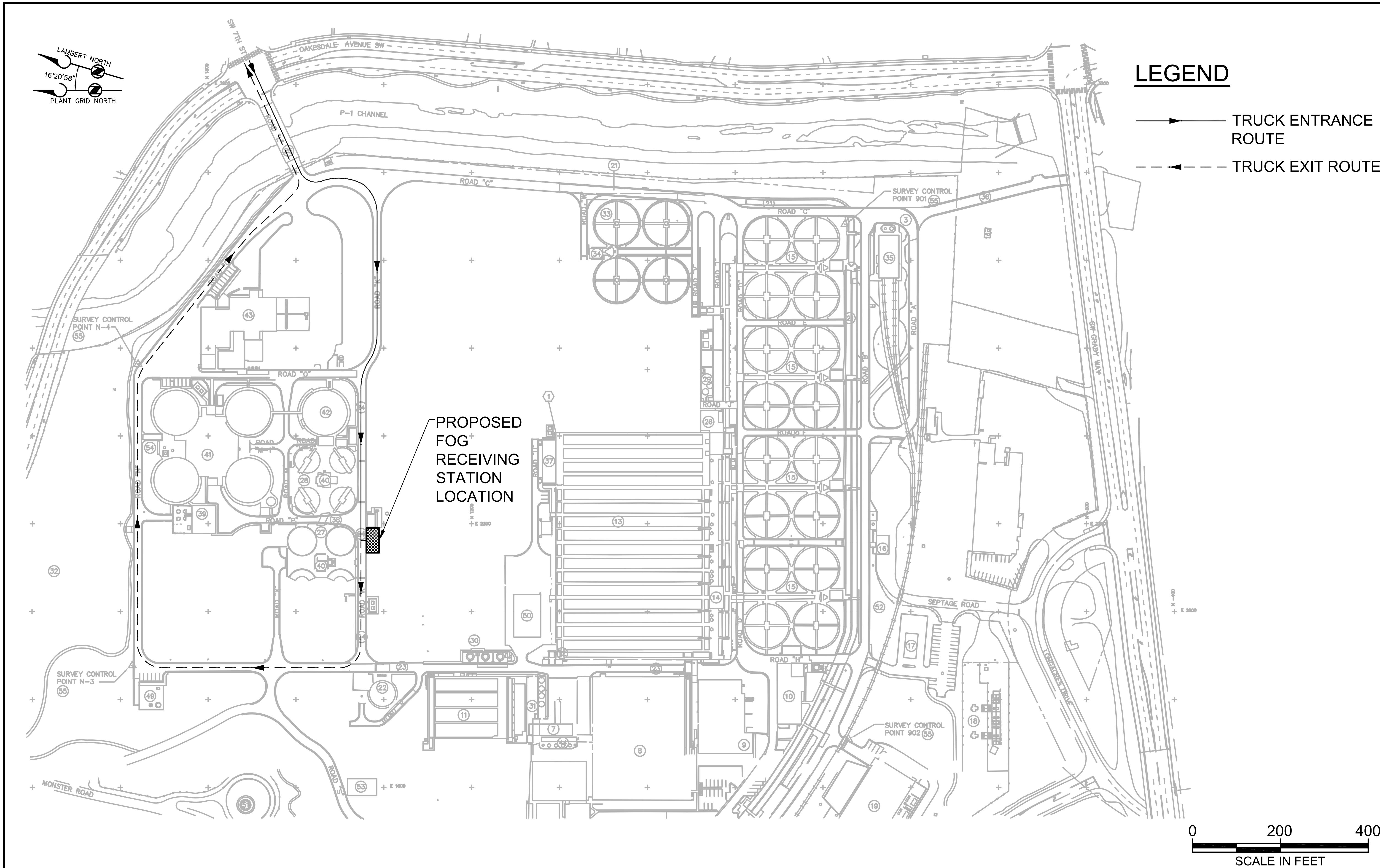


Figure 2-11
Process Flow Diagram



Site Plan.dwg

jmoffat

Nov 16, 2011 - 9:44am
P:\King County\141326 Mech-Elec On-Call_CAD\0-Project\Figures\Fig_2-19.dwg

Figure 2-19
Site Plan

Attachment B: Class 4 Cost Estimate

Brown AND Caldwell

5090 Brian Dr.
Parker, CO 80134
Tel: 303-921-0335
Fax: 303-805-1362

Memorandum

Date: November 14, 2011

To: Ian McKelvey, Seattle

cc: Chris Muller, Seattle

From: Dan Goodburn, Parker

Reviewed by: Butch Matthews, Jacksonville

Project Number: 141326-002-030

Subject: King County Grease Facility

Conceptual Design

Basis of Estimate of Probable Construction Revision

The Basis of Estimate Report for the subject project is attached. Please call me if you have questions or need additional information.

DG: dg

Enclosures (2)

1. Summary Estimate
2. Detailed Estimate

KING COUNTY GREASE FACILITY

Introduction

Brown and Caldwell (BC) is pleased to present this estimate of probable construction cost (estimate) prepared for the King County Grease Facility, Washington.

Summary

This Basis of Estimate contains the following information:

- Scope of work
- Background of this estimate
- Class of estimate
- Estimating methodology
- Direct cost development
- Indirect cost development
- Bidding assumptions
- Estimating assumptions
- Estimating exclusions
- Allowances for known but undefined work
- Contractor and other estimate markups

Scope of Work

This estimate identifies the probable construction cost for two phases of construction of a grease facility for King County, Washington. The phases are:

- Pilot Facility (Unit 1)
- Second Expansion (Units 2 through 4)

Background of this Estimate

The attached estimate of probable construction cost is based on documents dated October 2011, and further refinements dated November 14, 2011, received by the ESG. These documents are described as conceptual based on the current project progression, additional or updated scope and/or quantities, and ongoing discussions with the project team. Further information can be found in the detailed estimate reports.

Class of Estimate

In accordance with the Association for the Advancement of Cost Engineering International (AACE) criteria, this is a Class 4 estimate. A Class 4 estimate is defined as a Planning Level or Design Technical Feasibility Estimate. Typically, engineering is from 1 percent to 15 percent complete. Class 4 estimates are used to prepare planning level cost scopes or to evaluate alternatives in design conditions and form the base work for the Class 3 Project Budget or Funding Estimate.

Expected accuracy for Class 4 estimates typically range from -30 percent to +50 percent, depending on the technological complexity of the project, appropriate reference information, and the inclusion of an appropriate contingency determination. In unusual circumstances, ranges could exceed those shown.

Estimating Methodology

This estimate was prepared using quantity take-offs, vendor quotes, and equipment pricing furnished either by the project team or by the estimator. The estimate includes direct labor costs and anticipated productivity adjustments to labor, and equipment. Where possible, estimates for work anticipated to be performed by specialty subcontractors have been identified.

Construction labor crew and equipment hours were calculated from production rates contained in documents and electronic databases published by R.S. Means, Mechanical Contractors Association (MCA), National Electrical Contractors Association (NECA), and Rental Rate Blue Book for Construction Equipment (Blue Book).

This estimate was prepared using BC's estimating system, which consists of a Windows-based commercial estimating software engine using BC's material and labor database, historical project data, the latest vendor and material cost information, and other costs specific to the project locale.

Direct Cost Development

Costs associated with the General Provisions and the Special Provisions of the construction documents, which are collectively referred to as Contractor General Conditions (CGC), were based on the estimator's interpretation of the contract documents. The estimates for CGCs are divided into two groups: a time-related group (e.g., field personnel), and non-time-related group (e.g., bonds and insurance). Labor burdens such as health and welfare, vacation, union benefits, payroll taxes, and workers compensation insurance are included in the labor rates. No trade discounts were considered.

Indirect Cost Development

Local sales tax has been applied to material and equipment rentals. A percentage allowance for contractor's home office expense has been included in the overall rate markups. The rate is standard for this type of heavy construction and is based on typical percentages outlined in Means Heavy Construction Cost Data.

The contractor's cost for builders risk, general liability, and vehicle insurance has been included in this estimate. Based on historical data, this is typically two to four percent of the overall construction contract amount. These indirect costs have been included in this estimate as a percentage of the gross cost, and are added to the net totals after the net markups have been applied to the appropriate items.

Bidding Assumptions

The following bidding assumptions were considered in the development of this estimate.

1. Bidders must hold a valid, current Contractor's credentials, applicable to the type of project.

2. Bidders will develop estimates with a competitive approach to material pricing and labor productivity, and will not include allowances for changes, extra work, unforeseen conditions, or any other unplanned costs.
3. Estimated costs are based on a minimum of four bidders. Actual bid prices may increase for fewer bidders or decrease for a greater number of bidders.
4. Bidders will account for General Provisions and Special Provisions of the contract documents and will perform all work except that which will be performed by traditional specialty subcontractors as identified here:
   - Electrical

Estimating Assumptions

As the design progresses through different completion stages, it is customary for the estimator to make assumptions to account for details that may not be evident from the documents. The following assumptions were used in the development of this estimate.

1. Contractor performs the work during normal daylight hours, nominally 7 a.m. to 5 p.m., Monday through Friday, in an 8-hour shift. No allowance has been made for additional shift work or weekend work.
2. Contractor has complete access for lay-down areas and mobile equipment.
3. Equipment rental rates are based on verifiable pricing from the local project area rental yards, Blue Book rates, and/or rates contained in the estimating database.
4. Contractor markup is based on conventionally accepted values that have been adjusted for project-area economic factors.
5. Major equipment costs are based on both vendor supplied price quotes obtained by the project design team and/or estimators, and on historical pricing of like equipment.
6. Process equipment vendor training using vendors' standard Operations and Maintenance (O&M) material, is included in the purchase price of major equipment items where so stated in that quotation.
7. Bulk material quantities are based on manual quantity take-offs.
8. There is sufficient electrical power to feed the specified equipment. The local power company will supply power and transformers suitable for this facility.
9. Soils are of adequate nature to support the structures. No piles have been included in this estimate.
10. The facility is being investigated as a potential pilot facility with possible future expansion. A construction time frame is unknown. The phase estimates are shown in today's dollars. No cost escalation to construction mid-point is included.
11. The storage tanks are above grade reinforced concrete construction. The tank for the pilot stage is 17' diameter x 16' tall with 24" thick base slab and 16" thick wall section. The second expansion tank is 24' diameter x 24' tall with 24" thick base slab and 24" thick wall section.
12. Sumps are below grade reinforced concrete construction with 12" thick slab, wall and roof section. The pilot sump is 4' x 4' x 5' deep and the second expansion sump is 7' x 7' x 5' deep.
13. The sumps and tanks are coated inside with blended Amine cured epoxy coating for protection of the concrete surfaces.

14. The screens, pumps, and heat exchangers are located on an open air concrete slab on grade with thickened edge. All equipment is on raised equipment pads above the slab surface. No structures are included.
15. The present site is sloped and is grassed with small trees. The site will need to be leveled with a retaining wall to terminate the uphill slope.
16. Truck parking/staging is 4" thick asphalt paving including drive-over curb and gutter along the existing road.
17. Carbon canister odor control facilities are included for the sumps and tanks.

Estimating Exclusions

The following estimating exclusions were assumed in the development of this estimate.

1. Hazardous materials remediation and/or disposal.
2. O&M costs for the project with the exception of the vendor supplied O&M manuals.
3. Utility agency costs for incoming power modifications.
4. Permits beyond those normally needed for the type of project and project conditions.
5. Escalation to mid-point of construction.

Allowances for Known but Undefined Work

The following allowances were made in the development of this estimate.

1. Contractor General Conditions
2. Electrical/Instrumentation
3. Hot sludge flush connection
4. Pipe supports

Contractor and Other Estimate Markups

Contractor markup is based on conventionally accepted values which have been adjusted for project-area economic factors. Estimate markups are shown in Table 1.

Table 1. Estimate Markups

Item	Rate, percent
Net Cost Markups	
Labor (employer payroll burden)	8
Materials and process equipment	8
Equipment (construction-related)	8
Subcontractor	5
Sales Tax (State and local for materials, process equipment and construction equipment rentals, etc.)	9.5

Table 1. Estimate Markups	
Item	**Rate, percent**
Material Shipping and Handling	2
Escalation to Midpoint of Construction	0
Gross Cost Markups	
Contractor General Conditions	10
Start-up, Training and O&M	2
Construction Contingency	25
Builders Risk, Liability and Auto Insurance	2
Performance and Payment Bonds	1.5

Labor Markup. The labor rates used in the estimate were derived chiefly from the latest published State Prevailing Wage Rates. These include base rate paid to the laborer plus fringes. A labor burden factor is applied to these such that the final rates include all employer paid taxes. These taxes are FICA (7.7 percent covers social security plus Medicare), Workers Comp (which varies based on state, employer experience and history, etc.) and unemployment insurance. The result is fully loaded labor rates. In addition to the fully loaded labor rate, an overhead and profit markup is applied at the back end of the estimate. This covers payroll and accounting, estimator's wages, home office rent, advertising, and owner profit.

Materials and Process Equipment Markup. This markup consists of the additional cost to the contractor beyond the raw dollar amount for material and process equipment. This includes shop drawing preparation, submittal and/or re-submittal cost, purchasing and scheduling materials and equipment, accounting charges including invoicing and payment, inspection of received goods, receiving, storage, overhead and profit.

Equipment (Construction) Markup. This markup consists of the costs associated with operating the construction equipment used in the project. Most GCs will rent rather than own the equipment and then charge each project for its equipment cost. The equipment rental cost does not include fuel, delivery and pick-up charges, additional insurance requirements on rental equipment, accounting costs related to home office receiving invoices and payment. However, the crew rates used in the estimate do account for the equipment rental cost. Occasionally, larger contractors will have some or all of the equipment needed for the job, but in order to recoup their initial purchasing cost they will charge the project an internal rate for equipment use which is similar to the rental cost of equipment. The GC will apply an overhead and profit percentage to each individual piece of equipment whether rented or owned.

Subcontractor Markup. This markup consists of the GC's costs for subcontractors who perform work on the site. This includes costs associated with shop drawings, review of subcontractor's submittals, scheduling of subcontractor work, inspections, processing of payment requests, home office accounting, and overhead and profit on subcontracts.

Sales Tax (Materials, Process Equipment and Construction Equipment). This is the tax that the contractor must pay according to state and local tax laws. The percentage is applied to both the material and equipment the GC purchases as well as the cost for rental equipment. The percentage is based on the local rates in place at the time the estimate was prepared.

Contractor Startup, Training, and O&M Manuals. This cost markup is often confused with either vendor startup or owner startup. It is the cost the GC incurs on the project beyond the vendor startup and owner startup costs. The GC generally will have project personnel assigned to facilitate the installation, testing, startup, and O&M Manual preparation for equipment that is put into operation by either the vendor or owner. These project personnel often include an electrician, pipe fitter or millwright, and/or I&E technician. These personnel are not included in the basic crew makeup to install the equipment but are there to assist and trouble shoot the startup and proper running of the equipment. The GC also incurs a cost for startup for such things as consumables (oil, fuel, filters, etc.), startup drawings and schedules, startup meetings, and coordination with the plant personnel in other areas of the plant operation.

Builders Risk, Liability, and Vehicle Insurance. This percentage comprises all three items. There are many factors which make up this percentage, including the contractor's track record for claims in each of the categories. Another factor affecting insurance rates has been a dramatic price increase across the country over the past several years due to domestic and foreign influences. Consequently, in the construction industry we have observed a range of 0.5 to 1 percent for Builders Risk Insurance, 1 to 1.25 percent for General Liability Insurance, and 0.85 to 1 percent for Vehicle Insurance. Many factors affect each area of insurance, including project complexity, and contractor's requirements and history. Instead of using numbers from a select few contractors, we believe it is more prudent to use a combined 2 percent to better reflect the general costs across the country. Consequently, the actual cost could be higher or lower based on the bidder, region, insurance climate, and on the contractor's insurability at the time the project is bid.

Material Shipping and Handling. This can range from 2 percent to 6 percent, and is based on the type of project, material makeup of the project, and the region and location of the project. Material shipping and handling covers delivery costs from vendors, unloading costs (and in some instances loading and shipment back to vendors for rebuilt equipment), site paper work, and inspection of materials prior to unloading at the project site. BC typically adjusts this percentage by the amount of materials and whether vendors have included shipping costs in the quotes that were used to prepare the estimate. This cost also includes the GC's cost to obtain local supplies, e.g., oil, gaskets, and bolts that may be missing from the equipment or materials shipped.

Construction Contingency. The contingency factor covers unforeseen conditions, area economic factors, and general project complexity. This contingency is used to account for those factors that can not be addressed in each of the labor and/or material installation costs. Based on industry standards, completeness of the project documents, project complexity, the current design stage, and area factors, construction contingency can range from 10 percent to 50 percent.

Performance and Payment Bonds. Based on historical and industry data, this can range from 0.75 percent to 3 percent of the project total. There are several contributing factors including such items as size of the project, regional costs, contractor's historical record on similar projects, complexity, and current bonding limits. BC uses 1.5 percent for bonds, which we have determined to be reasonable for most heavy construction projects.

BROWN AND CALDWELL
Environmental Engineers & Consultants

SUMMARY ESTIMATE REPORT
WITH MARK-UPS ALLOCATED

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Project Number:	141326-002-030
BC Project Manager:	IAN McKELVEY
BC Office:	SEATTLE
Estimate Issue Number:	01
Estimate Original Issue Date:	NOVEMBER 8, 2011
Estimate Revision Number:	01
Estimate Revision Date:	11-14-11
Lead Estimator:	BOB FERGUSON/DAN GOODBURN
Estimate QA/QC Reviewer:	BUTCH MATTHEWS
Estimate QA/QC Date:	NOVEMBER 7, 2011

PROCESS LOCATION/AREA INDEX

PILOT FACILITY (UNIT 1)
- 01 - CIVIL/SITE WORK
- 02 - STRUCTURAL
- 03 - EQUIPMENT
- 04 - MECHANICAL
- 05 - ELECTRICAL/INSTRUMENTATION

SECOND EXPANSION (UNITS 2 THROUGH 4)
- 01 - CIVIL/SITE WORK
- 02 - STRUCTURAL
- 03 - EQUIPMENT
- 04 - MECHANICAL
- 05 - ELECTRICAL/INSTRUMENTATION

CONCEPTUAL ESTIMATE

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Description		Gross Total Costs
PILOT FACILITY (UNIT 1)		**922,522**
01 - CIVIL/SITE WORK		
01 - General Requirements		**795**
02 - Site Construction		**57,142**
03 - Concrete		**30,399**
15 - Mechanical		**75,819**
	01 - CIVIL/SITE WORK Total	**164,154**
02 - STRUCTURAL		
01 - General Requirements		**209**
02 - Site Construction		**15,264**
03 - Concrete		**125,909**
05 - Metals		**25,545**
08 - Doors & Windows		**2,215**
09 - Finishes		**44,156**
	02 - STRUCTURAL Total	**213,298**
03 - EQUIPMENT		
05 - Metals		**79,424**
11 - Equipment		**274,202**
	03 - EQUIPMENT Total	**353,625**
04 - MECHANICAL		
05 - Metals		**11,770**
09 - Finishes		**1,242**
15 - Mechanical		**67,525**
	04 - MECHANICAL Total	**80,536**
05 - ELECTRICAL/INSTRUMENTATION		
16 - Electrical		**110,908**
	05 - ELECTRICAL/INSTRUMENTATION Total	**110,908**
SECOND EXPANSION (UNITS 2 THROUGH 4)		**2,440,994**
01 - CIVIL/SITE WORK		

CONCEPTUAL ESTIMATE

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Description		Gross Total Costs
01 - General Requirements		517
02 - Site Construction		79,032
03 - Concrete		48,413
15 - Mechanical		289
	01 - CIVIL/SITE WORK Total	128,251
02 - STRUCTURAL		
01 - General Requirements		411
02 - Site Construction		30,398
03 - Concrete		259,997
05 - Metals		43,828
08 - Doors & Windows		2,215
09 - Finishes		102,288
	02 - STRUCTURAL Total	439,138
03 - EQUIPMENT		
05 - Metals		159,022
11 - Equipment		1,272,624
	03 - EQUIPMENT Total	1,431,645
04 - MECHANICAL		
05 - Metals		23,540
09 - Finishes		3,725
15 - Mechanical		125,169
	04 - MECHANICAL Total	152,434
05 - ELECTRICAL/INSTRUMENTATION		
16 - Electrical		289,526
	05 - ELECTRICAL/INSTRUMENTATION Total	289,526

DETAILED ESTIMATE REPORT

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Project Number:	141326-002-030
BC Project Manager:	IAN McKELVEY
BC Office:	SEATTLE
Estimate Issue Number:	01
Estimate Original Issue Date:	NOVEMBER 8, 2011
Estimate Revision Number:	01
Estimate Revision Date:	11-14-11
Lead Estimator:	BOB FERGUSON/DAN GOODBURN
Estimate QA/QC Reviewer:	BUTCH MATTHEWS
Estimate QA/QC Date:	NOVEMBER 7, 2011

PROCESS LOCATION/AREA INDEX

PILOT FACILITY (UNIT 1)
- **01 - CIVIL/SITE WORK**
- **02 - STRUCTURAL**
- **03 - EQUIPMENT**
- **04 - MECHANICAL**
- **05 - ELECTRICAL/INSTRUMENTATION**

SECOND EXPANSION (UNITS 2 THROUGH 4)
- **01 - CIVIL/SITE WORK**
- **02 - STRUCTURAL**
- **03 - EQUIPMENT**
- **04 - MECHANICAL**
- **05 - ELECTRICAL/INSTRUMENTATION**

CONCEPTUAL ESTIMATE

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	PILOT FACILITY (UNIT 1)									
	01 - CIVIL/SITE WORK									**100,067**
	01100 - Summary									
	01107700 - Topographical Surveys									
1400	Boundary & survey markers, crew for roadway layout, 4 person crew	0.1	days	2,113.05			72.59		2,185.64	112
	Summary Total									**112**
	01590 - Construction Aids									
	01590400 - General equipment rental without operators									
7030B	Rent trench box, 3000 lbs 6' x 8' - Rent per day	4.0	days				93.00		93.00	372
	Construction Aids Total									**372**
	02200 - Site Preparation									
	02220250 - Demolish, Remove Pavement And Curb									
6100	Demolish, remove pavement & curb, remove concrete curbs, reinforced, excludes hauling and disposal fees	33.0	LF	4.66			1.21		5.87	194
	02230300 - Selective Tree Removal									
3100	Selective clearing and grubbing, 8" to 12" diameter, remove selective trees, on site using chain saws and chipper, excludes stumps	1.0	EA	209.24			113.04		322.27	322
	02230500 - Stripping & Stockpiling Of Soil									
0600	Topsoil stripping and stockpiling, clay, dry and soft, ideal conditions, 200 H.P. dozer	101.9	CY	0.43			0.68		1.11	113
	Site Preparation Total									**629**
	02300 - Earthwork									
	02310100 - Finish Grading									
1050	Fine grading, fine grade for small irregular areas, to 15,000 S.Y.	110.0	SY	1.35			0.94		2.29	252
	02315120 - Backfill, Structural									
4420	**Backfill, structural, common earth, 200 H.P. dozer, 300' haul**	**704.9**	**L.C.Y.**	**0.94**			**1.48**		**2.42**	**1,707**
	02315210 - Borrow, Loading And/Or Spreading									

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
0500	Borrow, bank run gravel, haul 2 miles, haul, spread with 200 H.P. dozer	25.8	ton	1.45			1.95		3.40	88
	02315310 - Compaction, General									
5720	Compaction, 4 passes, 12" lifts, riding, sheepsfoot or wobbly wheel roller	18.3	E.C.Y.	0.26			0.44		0.70	13
7000	**Compaction, around structures and trenches, 2 passes, 18" wide, 6" lifts, walk behind, vibrating plate**	**375.6**	**E.C.Y.**	**1.97**			**0.16**		**2.13**	**800**
7220	Compaction, 3 passes, 18" wide, 12" lifts, walk behind, vibrating plate	7.4	E.C.Y.	1.05			0.10		1.16	9
7500	Compaction, 2 passes, 24" wide, 6" lifts, walk behind, vibrating roller	440.0	E.C.Y.	1.64			0.36		2.01	883
9010	Compaction, water for, 3000 gallon truck, 6 mile haul	18.3	E.C.Y.	0.66	1.15		0.55		2.36	43
	02315424 - Excavating, Bulk Bank Measure									
0250	Excavating, bulk bank measure, 1-1/2 C.Y. capacity = 100 C.Y./hour, backhoe, hydraulic, crawler mounted, excluding truck loading	1,020.0	B.C.Y.	0.90			0.99		1.88	1,921
	02315492 - Hauling									
0009	**Loading Trucks, F.E. Loader, 3 C.Y.**	**1,338.2**	**cuyd**	**0.71**			**1.07**		**1.78**	**2,385**
4498	**Cycle hauling(wait, load,travel, unload or dump & return) time per cycle, excavated or borrow, loose cubic yards, 25 min load/wait/unload, 20 CY truck, cycle 20 miles, 45 MPH, no loading equipment**	**1,338.2**	**L.C.Y.**	**2.55**			**3.45**		**6.00**	**8,028**
	02315610 - Excavating, Trench									
0060	Excavating, trench or continuous footing, common earth, 1/2 C.Y. excavator, 1' to 4' deep, excludes sheeting or dewatering	472.9	B.C.Y.	4.45			1.81		6.26	2,961
1000	Excavating, trench or continuous footing, common earth, 1-1/2 C.Y. excavator, 10' to 14' deep, excludes sheeting or dewatering	345.7	B.C.Y.	1.66			1.81		3.47	1,201
	02315640 - Utility Bedding									
0100	Fill by borrow and utility bedding, for pipe and conduit, crushed stone, 3/4" to 1/2", excludes compaction	173.0	L.C.Y.	8.55	38.00		2.22		48.77	8,437
	Earthwork Total									**28,727**
	02700 - Bases, Ballasts, Pavements & Appurtenances									
	02740315 - Asphaltic Concrete Pavement, Lots & Driveways									
0600	Asphaltic concrete, parking lots & driveways, base course, 4" thick, no asphalt hauling included	990.0	SF	0.24	1.52		0.21		1.97	1,949
	02770300 - Cement Concrete Curbs									

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
0435	Cast-in place concrete curbs & gutters, straight, wood forms, 0.066 C.Y. per L.F., 6" high curb, 6" thick gutter, 30" wide, includes concrete	33.0	LF	8.36	14.35				22.71	749
	02785250 - Fog Seal									
0400	Fog seal, sealcoating, petroleum resistant, under 1000 S.Y.	110.0	SY	1.17	1.40				2.57	283
	Bases, Ballasts, Pavements & Appurtenances Total									**2,981**
	02800 - Site Improvements And Amenities									
	02840800 - Parking Bumpers									
1300	Metal parking bumpers, pipe bollards, conc filled/painted, 8' L x 4' D hole, 6" diam.	4.0	EA	64.14	640.00		16.59		720.73	2,883
	Site Improvements And Amenities Total									**2,883**
	03100 - Concrete Forms & Accessories									
	03110430 - Forms In Place, Footings									
5150	C.I.P. concrete forms, footing, spread, plywood, 4 use, includes erecting, bracing, stripping and cleaning	1,735.0	sfca	4.44	0.58				5.02	8,705
	Concrete Forms & Accessories Total									**8,705**
	03200 - Concrete Reinforcement									
	03210600 - Reinforcing In Place									
0602	Reinforcing Steel, in place, slab on grade, #3 to #7, A615, grade 60, incl labor for accessories, excl material for accessories	3,946.0	lb	0.55	0.45				1.00	3,964
2000	Reinforcing steel, unload and sort, add to base	2.0	ton	39.28			7.78		47.06	93
2210	Reinforcing steel, crane cost for handling, average, add	2.0	ton	42.99			8.45		51.44	102
	Concrete Reinforcement Total									**4,160**
	03300 - Cast-In-Place Concrete									
	03310220 - Concrete, Ready Mix Normal Weight									
0300	Structural concrete, ready mix, normal weight, 4000 PSI, includes local aggregate, sand, Portland cement and water, delivered, excludes all additives and treatments	32.8	CY		103.00				103.00	3,382
	03310700 - Placing Concrete									

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
4650	Structural concrete, placing, slab on grade, pumped, over 6" thick, includes strike off & consolidation, excludes material	32.8	CY	18.38			4.42		22.80	749
	03350350 - Finishing Walls									
0150	Concrete finishing, walls, carborundum rub, wet, includes breaking ties and patching voids	798.0	SF	2.78					2.78	2,219
	Cast-In-Place Concrete Total									**6,350**
	15050 - Basic Materials & Methods									
	15050010 - Miscellaneous Mechanical									
0210	Hot sludge flush connection on conveyance line, allowance	1.0	each	201.80	650.00			1.00	852.80	853
	Basic Materials & Methods Total									**853**
	15100 - Building Services Piping									
	15110600 - Valves, Semi-Steel									
7030	Valves, semi-steel, lubricated plug valve, flanged, 200 lb., 4"	3.0	EA	443.96	430.00				873.96	2,622
	15120730 - Sleeves And Escutcheons									
0200	Sleeve, pipe, steel with water stop, 12" long, 6" diam. for 4" carrier pipe, includes link seal	1.0	EA	84.23	92.00				176.23	176
	Building Services Piping Total									**2,798**
	15200 - Process Piping									
	15200165 - Pipe, Glass Lined Ductile Iron									
0020	Piping, DI, glass lined, CL 50, 4" dia	750.0	lnft	13.31	37.98		2.25		53.54	40,156
	15200170 - Fittings, Glass Lined Ductile Iron									
0070	Fitting, DI, glass lined, 90 deg ell,4" dia	3.0	each	135.32	167.00				302.32	907
0200	Fitting, DI, glass lined, tee, 4" dia	1.0	each	202.90	231.23				434.14	434
	Process Piping Total									**41,498**

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	02 - STRUCTURAL									**134,154**
	01500 - Temporary Facilities & Controls									
	01540750 - Scaffolding									
6610	**Scaffolding, steel tubular, heavy duty shoring for elevated slab forms, floor area, rent/month of materials only, to 14'-8" high**	**2.9**	**Csf**		**43.00**				**43.00**	**125**
	Temporary Facilities & Controls Total									**125**
	02300 - Earthwork									
	02315120 - Backfill, Structural									
4420	**Backfill, structural, common earth, 200 H.P. dozer, 300' haul**	**363.0**	**L.C.Y.**	**0.94**			**1.48**		**2.42**	**879**
	02315310 - Compaction, General									
7000	**Compaction, around structures and trenches, 2 passes, 18" wide, 6" lifts, walk behind, vibrating plate**	**319.0**	**E.C.Y.**	**1.97**			**0.16**		**2.13**	**679**
7500	Compaction, 2 passes, 24" wide, 6" lifts, walk behind, vibrating roller	0.1	E.C.Y.	1.64			0.36		2.01	0
7520	Compaction, 3 passes, 24" wide, 6" lifts, walk behind, vibrating roller	23.6	E.C.Y.	2.47			0.54		3.01	71
7540	Compaction, 4 passes, 24" wide, 6" lifts, walk behind, vibrating roller	47.2	E.C.Y.	3.29			0.73		4.01	189
	02315424 - Excavating, Bulk Bank Measure									
0250	**Excavating, bulk bank measure, 1-1/2 C.Y. capacity = 100 C.Y./hour, backhoe, hydraulic, crawler mounted, excluding truck loading**	**328.1**	**B.C.Y.**	**0.90**			**0.99**		**1.88**	**618**
	02315492 - Hauling									
0009	**Loading Trucks, F.E. Loader, 3 C.Y.**	**157.1**	**cuyd**	**0.71**			**1.07**		**1.78**	**280**
4498	**Cycle hauling(wait, load,travel, unload or dump & return) time per cycle, excavated or borrow, loose cubic yards, 25 min load/wait/unload, 20 CY truck, cycle 20 miles, 45 MPH, no loading equipment**	**207.9**	**L.C.Y.**	**2.55**			**3.45**		**6.00**	**1,247**
	02315610 - Excavating, Trench									
0060	**Excavating, trench or continuous footing, common earth, 1/2 C.Y. excavator, 1' to 4' deep, excludes sheeting or dewatering**	**97.3**	**B.C.Y.**	**4.45**			**1.81**		**6.26**	**609**
	02315640 - Utility Bedding									
0100	**Fill by borrow and utility bedding, for pipe and conduit, crushed stone, 3/4" to 1/2", excludes compaction**	**99.0**	**L.C.Y.**	**8.55**	**38.00**		**2.22**		**48.77**	**4,827**

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	Earthwork Total									9,401
	03100 - Concrete Forms & Accessories									
	03110420 - Forms In Place, Elevated Slabs									
1500	C.I.P. concrete forms, elevated slab, flat plate, plywood, 15' to 20' high ceilings, includes shoring, erecting, bracing, stripping and cleaning	290.5	SF	5.75	1.03				6.78	1,970
	03110425 - Forms In Place, Equipment Foundations									
0050	C.I.P. concrete forms, equipment foundations, 2 use, includes erecting, bracing, stripping and cleaning	47.0	sfca	14.98	1.47				16.45	773
	03110445 - Forms In Place, Slab On Grade									
3050	C.I.P. concrete forms, slab on grade, edge, wood, 7" to 12" high, 4 use, includes erecting, bracing, stripping and cleaning	536.5	sfca	4.23	0.59				4.82	2,584
3550	C.I.P. concrete forms, slab on grade, depressed, edge, wood, 12" to 24" high, 4 use, includes erecting, bracing, stripping and cleaning	90.8	LF	10.53	0.79				11.32	1,028
	03110455 - Forms In Place, Walls									
2550	C.I.P. concrete forms, wall, job built, plywood, 8 to 16' high, 4 use, includes erecting, bracing, stripping and cleaning	1,818.8	sfca	7.21	0.63				7.84	14,257
	03150860 - Waterstop									
0600	Waterstop, PVC, ribbed, with center bulb, 3/8" thick x 9" wide	239.2	LF	3.85	4.48				8.33	1,992
	Concrete Forms & Accessories Total									22,606
	03200 - Concrete Reinforcement									
	03210600 - Reinforcing In Place									
0602	Reinforcing Steel, in place, slab on grade, #3 to #7, A615, grade 60, incl labor for accessories, excl material for accessories	13,793.4	lb	0.55	0.45				1.00	13,857
0702	Reinforcing Steel, in place, walls, #3 to #7, A615, grade 60, incl labor for accessories, excl material for accessories	8,807.2	lb	0.39	0.45				0.84	7,396
2000	Reinforcing steel, unload and sort, add to base	13.7	ton	39.28			7.78		47.06	647
2210	Reinforcing steel, crane cost for handling, average, add	13.7	ton	42.99			8.45		51.44	707
2420	Reinforcing steel, in place, dowels, deformed, 2' long, #5, A615, grade 60	89.0	EA	2.67	1.03				3.70	329

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
2450	**Reinforcing steel, in place, dowels, deformed, A615, grade 60, longer and heavier, add**	**4,688.1**	**lb**	**1.60**	**0.50**				**2.10**	**9,863**
	Concrete Reinforcement Total									32,799
	03300 - Cast-In-Place Concrete									
	03310220 - Concrete, Ready Mix Normal Weight									
0300	**Structural concrete, ready mix, normal weight, 4000 PSI, includes local aggregate, sand, Portland cement and water, delivered, excludes all additives and treatments**	**126.5**	**CY**		**103.00**				**103.00**	**13,027**
	03310700 - Placing Concrete									
1500	Structural concrete, placing, elevated slab, pumped, 6" to 10" thick, includes strike off & consolidation, excludes material	1.3	CY	21.19			5.10		26.29	35
1550	Structural concrete, placing, elevated slab, with crane and bucket, 6" to 10" thick, includes strike off & consolidation, excludes material	9.4	CY	35.32			15.75		51.07	481
4650	**Structural concrete, placing, slab on grade, pumped, over 6" thick, includes strike off & consolidation, excludes material**	**71.8**	**CY**	**18.38**			**4.42**		**22.80**	**1,637**
5350	**Structural concrete, placing, walls, pumped, 15" thick, includes strike off & consolidation, excludes material**	**43.9**	**CY**	**28.25**			**6.79**		**35.05**	**1,539**
	03350300 - Finishing Floors									
0150	**Concrete finishing, floors, basic finishing for unspecified flatwork, bull float, manual float & broom finish, includes edging and joints, excludes placing, striking off & consolidating**	**1,954.0**	**SF**	**0.74**					**0.74**	**1,439**
	03350350 - Finishing Walls									
0150	**Concrete finishing, walls, carborundum rub, wet, includes breaking ties and patching voids**	**1,801.8**	**SF**	**2.78**					**2.78**	**5,011**
0750	**Concrete finishing, walls, sandblast, heavy penetration**	**113.0**	**SF**	**4.18**	**1.46**		**0.54**		**6.18**	**698**
	Cast-In-Place Concrete Total									23,867
	05050 - Basic Metal Materials & Methods									
	05090340 - Drilling									
0400	**Concrete impact drilling, for anchors, up to 4" D, 5/8" dia, in concrete or brick walls and floors, incl bit & layout, excl anchor**	**89.0**	**EA**	**10.04**	**0.07**				**10.11**	**900**
	05090540 - Machinery Anchors									

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
0800	**Machinery anchor, heavy duty, 1" dia stud & bolt, incl sleeve, floating base nut, lower stud & coupling nut, fiber plug, connecting stud, washer & nut**	**24.0**	**EA**	**60.73**	**100.00**		**5.65**		**166.38**	**3,993**
	Basic Metal Materials & Methods Total									**4,893**
	05500 - Metal Fabrications									
	05514500 - Ladder									
0300	Ladder, shop fabricated, aluminum, 20" W, bolted to concrete, incl cage	16.0	vlft	47.76	111.00		2.26		161.02	2,576
0400	Ladder, shop fabricated, aluminum, 20" W, bolted to concrete, excl cage	6.0	vlft	27.97	48.00		1.33		77.30	464
	05520700 - Railing, Pipe,									
0210	Railing, pipe, aluminum, clear finish, 3 rails, 3'-6" high, posts @ 5' O.C., 1-1/2" dia, shop fabricated	84.0	LF	17.36	65.50		0.83		83.69	7,030
	05530300 - Floor Grating, Aluminum									
0132	Floor grating, aluminum, 1-1/2" x 3/16" bearing bars @ 1-3/16" O.C., cross bars @ 4" O.C., up to 300 S.F., field fabricated from panels	12.0	SF	3.40	41.50		0.17		45.06	541
	05530360 - Grating Frame									
0020	Grating frame, aluminum, 1" to 1-1/2" D, field fabricated	14.0	LF	8.29	3.44				11.73	164
	Metal Fabrications Total									**10,775**
	08300 - Specialty Doors									
	08310350 - Floor, Industrial									
3020ds	Doors, specialty, access, floor, industrial, aluminum, Gas/Watertight, H-20, single leaf, 3' x 3'	1.0	Opng	193.14	1,147.00				1,340.14	1,340
	Specialty Doors Total									**1,340**
	09900 - Paints & Coatings									
	09910641 - B & C Coatings									
0092bc	Coatings & paints, B & C coating system EA-2 (Blended Amine Cured Epoxy, conc, masonry)	1,210.0	sqft	19.93	3.50				23.43	28,348
	Paints & Coatings Total									**28,348**

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	03 - EQUIPMENT									**211,899**
	05500 - Metal Fabrications									
	05580950 - Miscellaneous Fabrication									
0100bc	Trash rack, 1'x1'x2', carbon steel, compl incl frame	1.0	each	47.59	250.00		2.26		299.86	300
0130bc	Odor control, sump covers, alum., removable,with support steel	16.0	sqft	152.85	33.95				186.80	2,989
0130bc	Odor control, tank covers, alum., removable,with support steel	254.5	sqft	152.85	33.95				186.80	47,542
	Metal Fabrications Total									**50,830**
	11000 - Equipment									
	11000100 - Process Equipment									
0120	Odor control, carbon canister, complete with fan	1.0	each	5,615.36	40,000.00				45,615.36	45,615
0460	Mechanical screen, 275 gpm, IPEC TLT 100, complete	1.0	each	9,782.40	43,000.00				52,782.40	52,782
9999	Heat Exchanger, 333 gpm, complete	1.0	each	5,209.92	20,000.00		684.00		25,893.92	25,894
	11000900 - Pumps, general utility									
0210	Pump, cntfgl, horiz mtd, end suct,vert splt,sgl stg,300GPM,15HP,2"D	1.0	each	1,304.82	3,925.00				5,229.82	5,230
0220	Pump, circulation, chopper, centrifugal, 333GPM,10HP	1.0	each	1,413.56	6,500.00				7,913.56	7,914
	11001000 - Pumps miscellaneous									
0131DS	Progressive cavity pump, 13 GPM, 5 HP	1.0	each	1,667.00	11,800.00				13,467.00	13,467
	11001100 - Pumps submersible									
0010	Wastewater, submersible chopper,150 gpm,guide rails, base elbow	1.0	each	1,408.61	8,550.00		207.66		10,166.27	10,166
	Equipment Total									**161,068**

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	04 - MECHANICAL									**48,488**
	05500 - Metal Fabrications									
	05580950 - Miscellaneous Fabrication									
0020bc	Pump mounting base plate, complete w/ anchor bolts, 8 sf	3.0	each	733.68	1,671.17				2,404.85	7,215
	Metal Fabrications Total									**7,215**
	09900 - Paints & Coatings									
	09910641 - B & C Coatings									
0020bc	Coatings & paints, B & C coating system E-2 (Epoxy, metal pipe)	400.0	sqft	0.81	1.11				1.92	769
	Paints & Coatings Total									**769**
	15050 - Basic Materials & Methods									
	15050010 - Miscellaneous Mechanical									
0040	Kam-lok, quick disconnect, w/cap, 6", stainless steel	2.0	each	184.25	610.64				794.89	1,590
0150	Utility stations, complete w/ valve, hose, rack,signage	1.0	each	372.89	371.37				744.27	744
	15060300 - Pipe Hangers And Supports									
9070	Pipe supports, allowance	1.0	EA		4,000.00				4,000.00	4,000
	15080600 - Piping Insulation									
6940	Insulation, pipe covering (price copper tube one size less than I.P.S.), fiberglass with all service jacket, 1" wall, 4" iron pipe size	110.0	LF	6.59	2.27				8.86	974
	Basic Materials & Methods Total									**7,308**
	15100 - Building Services Piping									
	15108520 - Pipe, Plastic									
4460	Pipe, plastic, PVC, small bore, hose bib and washdown, allowance	1.0	lsum	700.00	700.00				1,400.00	1,400
	15110200 - Valves, Iron Body									
5560	Valves, iron body, swing check, threaded, 125 lb., 4"	4.0	EA	133.01	1,225.00				1,358.01	5,432
	15110600 - Valves, Semi-Steel									
7030	Valves, semi-steel, lubricated plug valve, flanged, 200 lb., 4"	6.0	EA	443.96	385.00				828.96	4,974

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	Building Services Piping Total									**11,806**
	15200 - Process Piping									
	15200032 - Flanges, Ductile Iron									
0060	Stl ftg, gskt & bolt set, 150#, 4" pipe	14.0	each	87.74	8.70				96.44	1,350
	15200045 - Pipe, Fiberglass Reinforced (FRP)									
B84Y	Odor control, piping allowance	1.0	ea	2,193.50	3,500.00				5,693.50	5,694
	15200165 - Pipe, Glass Lined Ductile Iron									
0020	Piping, DI, glass lined, CL 50, 4" dia	110.0	lnft	13.31	37.98		2.25		53.54	5,890
	15200170 - Fittings, Glass Lined Ductile Iron									
0070	Fitting, DI, glass lined, 90 deg ell,4" dia	9.0	each	135.32	167.00				302.32	2,721
0140	Fitting, DI, glass lined, 45 deg ell,4" dia	1.0	each	135.32	176.18				311.49	311
0200	Fitting, DI, glass lined, tee, 4" dia	2.0	each	202.90	231.23				434.14	868
	15200212 - Pipe, 316 Stainless Steel									
0150	Pipe, SS, A778, weld, Sched. 10S, type 316L, 4" dia.	10.0	lnft	26.67	16.64		0.67		43.99	440
	15200330 - Flexible Connectors									
301	Connectors, flex, dismantling Joint, 4"	3.0	each	197.41	573.57				770.99	2,313
	Process Piping Total									**19,587**
	15700 - Heating/Ventilating/Air Conditioning Equipment									
	15760250 - Electric Heating									
4050	Electric heating, heat trace system, 400 degree, 115 V, 10 watts per L.F.	110.0	LF	1.09	7.35				8.44	928
	Heating/Ventilating/Air Conditioning Equipment Total									**928**
	15950 - Testing/Adjusting/Balancing									
	15955700 - Piping, Testing									
0160	Pipe testing, nondestructive hydraulic pressure test	1.0	EA	875.78					875.78	876
	Testing/Adjusting/Balancing Total									**876**

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	05 - ELECTRICAL/INSTRUMENTATION									**74,200**
	16000 - Electrical and Instrumentation									
	16000000 - Electrical and Instrumentation									
0001	Electrical and Instrumentation Subcontract	1.0	lsum			74,200.00			74,200.00	74,200
	Electrical and Instrumentation Total									**74,200**

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	SECOND EXPANSION (UNITS 2 THROUGH 4)									
	01 - CIVIL/SITE WORK									**79,837**
	01100 - Summary									
	01107700 - Topographical Surveys									
1400	Boundary & survey markers, crew for roadway layout, 4 person crew	0.2	days	2,113.05			72.59		2,185.64	335
	Summary Total									**335**
	02200 - Site Preparation									
	02220250 - Demolish, Remove Pavement And Curb									
6100	Demolish, remove pavement & curb, remove concrete curbs, reinforced, excludes hauling and disposal fees	99.0	LF	4.66			1.21		5.87	582
	02230300 - Selective Tree Removal									
3100	Selective clearing and grubbing, 8" to 12" diameter, remove selective trees, on site using chain saws and chipper, excludes stumps	1.0	EA	209.24			113.04		322.27	322
	02230500 - Stripping & Stockpiling Of Soil									
0600	Topsoil stripping and stockpiling, clay, dry and soft, ideal conditions, 200 H.P. dozer	201.9	CY	0.43			0.68		1.11	225
	Site Preparation Total									**1,128**
	02300 - Earthwork									
	02310100 - Finish Grading									
1050	Fine grading, fine grade for small irregular areas, to 15,000 S.Y.	330.0	SY	1.35			0.94		2.29	756
	02315120 - Backfill, Structural									
4420	Backfill, structural, common earth, 200 H.P. dozer, 300' haul	779.4	L.C.Y.	0.94			1.48		2.42	1,888
	02315210 - Borrow, Loading And/Or Spreading									
0500	Borrow, bank run gravel, haul 2 miles, haul, spread with 200 H.P. dozer	77.5	ton	1.45			1.95		3.40	264
	02315310 - Compaction, General									
5720	Compaction, 4 passes, 12" lifts, riding, sheepsfoot or wobbly wheel roller	55.0	E.C.Y.	0.26			0.44		0.70	38
7220	Compaction, 3 passes, 18" wide, 12" lifts, walk behind, vibrating plate	11.8	E.C.Y.	1.05			0.10		1.16	14

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
7500	Compaction, 2 passes, 24" wide, 6" lifts, walk behind, vibrating roller	701.4	E.C.Y.	1.64			0.36		2.01	1,407
9010	Compaction, water for, 3000 gallon truck, 6 mile haul	55.0	E.C.Y.	0.66	1.15		0.55		2.36	130
	02315424 - Excavating, Bulk Bank Measure									
0250	Excavating, bulk bank measure, 1-1/2 C.Y. capacity = 100 C.Y./hour, backhoe, hydraulic, crawler mounted, excluding truck loading	2,020.0	B.C.Y.	0.90			0.99		1.88	3,804
	02315492 - Hauling									
0009	**Loading Trucks, F.E. Loader, 3 C.Y.**	**2,182.9**	**cuyd**	**0.71**			**1.07**		**1.78**	**3,890**
4498	**Cycle hauling(wait, load,travel, unload or dump & return) time per cycle, excavated or borrow, loose cubic yards, 25 min load/wait/unload, 20 CY truck, cycle 20 miles, 45 MPH, no loading equipment**	**2,182.9**	**L.C.Y.**	**2.55**			**3.45**		**6.00**	**13,096**
	02315610 - Excavating, Trench									
0060	Excavating, trench or continuous footing, common earth, 1/2 C.Y. excavator, 1' to 4' deep, excludes sheeting or dewatering	753.8	B.C.Y.	4.45			1.81		6.26	4,719
	Earthwork Total									**30,005**
	02700 - Bases, Ballasts, Pavements & Appurtenances									
	02740315 - Asphaltic Concrete Pavement, Lots & Driveways									
0600	Asphaltic concrete, parking lots & driveways, base course, 4" thick, no asphalt hauling included	2,970.0	SF	0.24	1.52		0.21		1.97	5,846
	02770300 - Cement Concrete Curbs									
0435	Cast-in place concrete curbs & gutters, straight, wood forms, 0.066 C.Y. per L.F., 6" high curb, 6" thick gutter, 30" wide, includes concrete	99.0	LF	8.36	14.35				22.71	2,248
	02785250 - Fog Seal									
0400	Fog seal, sealcoating, petroleum resistant, under 1000 S.Y.	330.0	SY	1.17	1.40				2.57	848
	Bases, Ballasts, Pavements & Appurtenances Total									**8,942**
	02800 - Site Improvements And Amenities									
	02840800 - Parking Bumpers									
1300	Metal parking bumpers, pipe bollards, conc filled/painted, 8' L x 4' D hole, 6" diam.	12.0	EA	64.14	640.00		16.59		720.73	8,649
	Site Improvements And Amenities Total									**8,649**

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	03100 - Concrete Forms & Accessories									
	03110430 - Forms In Place, Footings									
5150	C.I.P. concrete forms, footing, spread, plywood, 4 use, includes erecting, bracing, stripping and cleaning	2,762.0	sfca	4.44	0.58				5.02	13,857
	Concrete Forms & Accessories Total									**13,857**
	03200 - Concrete Reinforcement									
	03210600 - Reinforcing In Place									
0602	Reinforcing Steel, in place, slab on grade, #3 to #7, A615, grade 60, incl labor for accessories, excl material for accessories	6,280.9	lb	0.55	0.45				1.00	6,310
2000	Reinforcing steel, unload and sort, add to base	3.2	ton	39.28			7.78		47.06	149
2210	Reinforcing steel, crane cost for handling, average, add	3.2	ton	42.99			8.45		51.44	163
	Concrete Reinforcement Total									**6,621**
	03300 - Cast-In-Place Concrete									
	03310220 - Concrete, Ready Mix Normal Weight									
0300	Structural concrete, ready mix, normal weight, 4000 PSI, includes local aggregate, sand, Portland cement and water, delivered, excludes all additives and treatments	52.3	CY		103.00				103.00	5,392
	03310700 - Placing Concrete									
4650	Structural concrete, placing, slab on grade, pumped, over 6" thick, includes strike off & consolidation, excludes material	52.3	CY	18.38			4.42		22.80	1,193
	03350350 - Finishing Walls									
0150	Concrete finishing, walls, carborundum rub, wet, includes breaking ties and patching voids	1,272.0	SF	2.78					2.78	3,537
	Cast-In-Place Concrete Total									**10,122**
	15100 - Building Services Piping									
	15120730 - Sleeves And Escutcheons									
0200	Sleeve, pipe, steel with water stop, 12" long, 6" diam. for 4" carrier pipe, includes link seal	1.0	EA	84.23	92.00				176.23	176
	Building Services Piping Total									**176**

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	02 - STRUCTURAL									**276,207**
	01500 - Temporary Facilities & Controls									
	01540750 - Scaffolding									
6610	**Scaffolding, steel tubular, heavy duty shoring for elevated slab forms, floor area, rent/month of materials only, to 14'-8" high**	**5.7**	**Csf**		**43.00**				**43.00**	**246**
	Temporary Facilities & Controls Total									**246**
	02300 - Earthwork									
	02315120 - Backfill, Structural									
4420	**Backfill, structural, common earth, 200 H.P. dozer, 300' haul**	**427.4**	**L.C.Y.**	**0.94**			**1.48**		**2.42**	**1,035**
	02315310 - Compaction, General									
7000	**Compaction, around structures and trenches, 2 passes, 18" wide, 6" lifts, walk behind, vibrating plate**	**392.6**	**E.C.Y.**	**1.97**			**0.16**		**2.13**	**836**
7500	Compaction, 2 passes, 24" wide, 6" lifts, walk behind, vibrating roller	0.6	E.C.Y.	1.64			0.36		2.01	1
7520	Compaction, 3 passes, 24" wide, 6" lifts, walk behind, vibrating roller	65.3	E.C.Y.	2.47			0.54		3.01	197
7540	Compaction, 4 passes, 24" wide, 6" lifts, walk behind, vibrating roller	130.6	E.C.Y.	3.29			0.73		4.01	524
	02315424 - Excavating, Bulk Bank Measure									
0250	**Excavating, bulk bank measure, 1-1/2 C.Y. capacity = 100 C.Y./hour, backhoe, hydraulic, crawler mounted, excluding truck loading**	**420.3**	**B.C.Y.**	**0.90**			**0.99**		**1.88**	**791**
	02315492 - Hauling									
0009	**Loading Trucks, F.E. Loader, 3 C.Y.**	**366.8**	**cuyd**	**0.71**			**1.07**		**1.78**	**654**
4498	**Cycle hauling(wait, load,travel, unload or dump & return) time per cycle, excavated or borrow, loose cubic yards, 25 min load/wait/unload, 20 CY truck, cycle 20 miles, 45 MPH, no loading equipment**	**431.9**	**L.C.Y.**	**2.55**			**3.45**		**6.00**	**2,591**
	02315610 - Excavating, Trench									
0060	**Excavating, trench or continuous footing, common earth, 1/2 C.Y. excavator, 1' to 4' deep, excludes sheeting or dewatering**	**237.4**	**B.C.Y.**	**4.45**			**1.81**		**6.26**	**1,487**
	02315640 - Utility Bedding									
0100	**Fill by borrow and utility bedding, for pipe and conduit, crushed stone, 3/4" to 1/2", excludes compaction**	**216.9**	**L.C.Y.**	**8.55**	**38.00**		**2.22**		**48.77**	**10,577**

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	Earthwork Total									18,692
	03100 - Concrete Forms & Accessories									
	03110420 - Forms In Place, Elevated Slabs									
1500	C.I.P. concrete forms, elevated slab, flat plate, plywood, 15' to 20' high ceilings, includes shoring, erecting, bracing, stripping and cleaning	571.9	SF	5.75	1.03				6.78	3,879
	03110425 - Forms In Place, Equipment Foundations									
0050	C.I.P. concrete forms, equipment foundations, 2 use, includes erecting, bracing, stripping and cleaning	111.0	sfca	14.98	1.47				16.45	1,826
	03110445 - Forms In Place, Slab On Grade									
3050	C.I.P. concrete forms, slab on grade, edge, wood, 7" to 12" high, 4 use, includes erecting, bracing, stripping and cleaning	846.5	sfca	4.23	0.59				4.82	4,077
3550	C.I.P. concrete forms, slab on grade, depressed, edge, wood, 12" to 24" high, 4 use, includes erecting, bracing, stripping and cleaning	124.8	LF	10.53	0.79				11.32	1,413
	03110455 - Forms In Place, Walls									
2550	C.I.P. concrete forms, wall, job built, plywood, 8 to 16' high, 4 use, includes erecting, bracing, stripping and cleaning	3,748.3	sfca	7.21	0.63				7.84	29,384
	03150860 - Waterstop									
0600	Waterstop, PVC, ribbed, with center bulb, 3/8" thick x 9" wide	339.6	LF	3.85	4.48				8.33	2,829
	Concrete Forms & Accessories Total									43,408
	03200 - Concrete Reinforcement									
	03210600 - Reinforcing In Place									
0602	Reinforcing Steel, in place, slab on grade, #3 to #7, A615, grade 60, incl labor for accessories, excl material for accessories	30,760.0	lb	0.55	0.45				1.00	30,902
0702	Reinforcing Steel, in place, walls, #3 to #7, A615, grade 60, incl labor for accessories, excl material for accessories	18,041.0	lb	0.39	0.45				0.84	15,150
2000	Reinforcing steel, unload and sort, add to base	27.7	ton	39.28			7.78		47.06	1,303
2210	Reinforcing steel, crane cost for handling, average, add	27.7	ton	42.99			8.45		51.44	1,424
2420	Reinforcing steel, in place, dowels, deformed, 2' long, #5, A615, grade 60	211.0	EA	2.67	1.03				3.70	780

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
2450	**Reinforcing steel, in place, dowels, deformed, A615, grade 60, longer and heavier, add**	**6,087.0**	**lb**	**1.60**	**0.50**				**2.10**	**12,807**
	Concrete Reinforcement Total									62,366
	03300 - Cast-In-Place Concrete									
	03310220 - Concrete, Ready Mix Normal Weight									
0300	**Structural concrete, ready mix, normal weight, 4000 PSI, includes local aggregate, sand, Portland cement and water, delivered, excludes all additives and treatments**	**314.6**	**CY**		**103.00**				**103.00**	**32,404**
	03310700 - Placing Concrete									
1500	Structural concrete, placing, elevated slab, pumped, 6" to 10" thick, includes strike off & consolidation, excludes material	3.0	CY	21.19			5.10		26.29	79
1550	Structural concrete, placing, elevated slab, with crane and bucket, 6" to 10" thick, includes strike off & consolidation, excludes material	18.2	CY	35.32			15.75		51.07	928
4650	**Structural concrete, placing, slab on grade, pumped, over 6" thick, includes strike off & consolidation, excludes material**	**159.8**	**CY**	**18.38**			**4.42**		**22.80**	**3,642**
5350	**Structural concrete, placing, walls, pumped, 15" thick, includes strike off & consolidation, excludes material**	**133.6**	**CY**	**28.25**			**6.79**		**35.05**	**4,684**
	03350300 - Finishing Floors									
0150	**Concrete finishing, floors, basic finishing for unspecified flatwork, bull float, manual float & broom finish, includes edging and joints, excludes placing, striking off & consolidating**	**4,810.1**	**SF**	**0.74**					**0.74**	**3,544**
	03350350 - Finishing Walls									
0150	**Concrete finishing, walls, carborundum rub, wet, includes breaking ties and patching voids**	**3,747.3**	**SF**	**2.78**					**2.78**	**10,421**
0750	**Concrete finishing, walls, sandblast, heavy penetration**	**299.0**	**SF**	**4.18**	**1.46**		**0.54**		**6.18**	**1,847**
	Cast-In-Place Concrete Total									57,549
	05050 - Basic Metal Materials & Methods									
	05090340 - Drilling									
0400	**Concrete impact drilling, for anchors, up to 4" D, 5/8" dia, in concrete or brick walls and floors, incl bit & layout, excl anchor**	**211.0**	**EA**	**10.04**	**0.07**				**10.11**	**2,133**
	05090540 - Machinery Anchors									

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
0800	**Machinery anchor, heavy duty, 1" dia stud & bolt, incl sleeve, floating base nut, lower stud & coupling nut, fiber plug, connecting stud, washer & nut**	**52.0**	**EA**	**60.73**	**100.00**		**5.65**		**166.38**	**8,652**
	Basic Metal Materials & Methods Total									**10,785**
	05500 - Metal Fabrications									
	05514500 - Ladder									
0300	Ladder, shop fabricated, aluminum, 20" W, bolted to concrete, incl cage	24.0	vlft	47.76	111.00		2.26		161.02	3,864
0400	Ladder, shop fabricated, aluminum, 20" W, bolted to concrete, excl cage	6.0	vlft	27.97	48.00		1.33		77.30	464
	05520700 - Railing, Pipe,									
0210	Railing, pipe, aluminum, clear finish, 3 rails, 3'-6" high, posts @ 5' O.C., 1-1/2" dia, shop fabricated	116.0	LF	17.36	65.50		0.83		83.69	9,708
	05530300 - Floor Grating, Aluminum									
0132	Floor grating, aluminum, 1-1/2" x 3/16" bearing bars @ 1-3/16" O.C., cross bars @ 4" O.C., up to 300 S.F., field fabricated from panels	36.0	SF	3.40	41.50		0.17		45.06	1,622
	05530360 - Grating Frame									
0020	Grating frame, aluminum, 1" to 1-1/2" D, field fabricated	42.0	LF	8.29	3.44				11.73	493
	Metal Fabrications Total									**16,151**
	08300 - Specialty Doors									
	08310350 - Floor, Industrial									
3020ds	Doors, specialty, access, floor, industrial, aluminum, Gas/Watertight, H-20, single leaf, 3' x 3'	1.0	Opng	193.14	1,147.00				1,340.14	1,340
	Specialty Doors Total									**1,340**
	09900 - Paints & Coatings									
	09910641 - B & C Coatings									
0092bc	Coatings & paints, B & C coating system EA-2 (Blended Amine Cured Epoxy, conc, masonry)	2,803.0	sqft	19.93	3.50				23.43	65,669
	Paints & Coatings Total									**65,669**

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	03 - EQUIPMENT									**843,375**
	05500 - Metal Fabrications									
	05580950 - Miscellaneous Fabrication									
0100bc	Trash rack, 1'x1'x2', carbon steel, compl incl frame	3.0	each	47.59	250.00		2.26		299.86	900
0130bc	Odor control, sump covers, alum., removable,with support steel	49.0	sqft	152.85	33.95				186.80	9,153
0130bc	Odor control, tank covers, alum., removable,with support steel	490.9	sqft	152.85	33.95				186.80	91,702
	Metal Fabrications Total									**101,755**
	11000 - Equipment									
	11000100 - Process Equipment									
0120	Odor control, carbon canister, complete with fan	1.0	each	5,615.36	40,000.00				45,615.36	45,615
0460	Mechanical screen, 275 gpm, IPEC TLT 100, complete	3.0	each	9,782.40	43,000.00				52,782.40	158,347
9999	Heat Exchanger, 1000 gpm, complete	1.0	each	6,078.24	35,000.00		798.00		41,876.24	41,876
	Scum concentrator	1.0	ea	12,445.92	375,000.00		1,359.71		388,805.63	388,806
	11000900 - Pumps, general utility									
0210	Pump, cntfgl, horiz mtd, end suct,vert splt,sgl stg,300GPM,15HP,2"D	1.0	each	1,304.82	3,925.00				5,229.82	5,230
0260	Pump, circulation, chopper, centrifugal, 1000GPM,30HP	2.0	each	3,392.53	9,700.00				13,092.53	26,185
	11001000 - Pumps miscellaneous									
0131DS	Progressive cavity pump, 85 GPM, 20 HP, (Digester Feed)	2.0	each	2,000.40	14,900.00				16,900.40	33,801
0131DS	Progressive cavity pump, 40 GPM, 10 HP, (FOG Transfer)	1.0	each	1,125.22	10,135.88				11,261.11	11,261
	11001100 - Pumps submersible									
0010	Wastewater, submersible chopper,150 gpm,guide rails, base elbow	3.0	each	1,408.61	8,550.00		207.66		10,166.27	30,499
	Equipment Total									**741,620**

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	04 - MECHANICAL									**91,986**
	05500 - Metal Fabrications									
	05580950 - Miscellaneous Fabrication									
0020bc	Pump mounting base plate, complete w/ anchor bolts, 8 sf	6.0	each	733.68	1,671.17				2,404.85	14,429
	Metal Fabrications Total									**14,429**
	09900 - Paints & Coatings									
	09910641 - B & C Coatings									
0020bc	Coatings & paints, B & C coating system E-2 (Epoxy, metal pipe)	1,200.0	sqft	0.81	1.11				1.92	2,306
	Paints & Coatings Total									**2,306**
	15050 - Basic Materials & Methods									
	15050010 - Miscellaneous Mechanical									
0040	Kam-lok, quick disconnect, w/cap, 6", stainless steel	6.0	each	184.25	610.64				794.89	4,769
0150	Utility stations, complete w/ valve, hose, rack,signage	3.0	each	372.89	371.37				744.27	2,233
	15060300 - Pipe Hangers And Supports									
9070	Pipe supports, allowance	1.0	EA		5,000.00				5,000.00	5,000
	15080600 - Piping Insulation									
6940	Insulation, pipe covering (price copper tube one size less than I.P.S.), fiberglass with all service jacket, 1" wall, 4" iron pipe size	260.0	LF	6.59	2.27				8.86	2,303
	Basic Materials & Methods Total									**14,305**
	15100 - Building Services Piping									
	15108520 - Pipe, Plastic									
4460	Pipe, plastic, PVC, small bore, hose bib and washdown, allowance	1.0	lsum	2,100.00	2,100.00				4,200.00	4,200
	15110200 - Valves, Iron Body									
5560	Valves, iron body, swing check, threaded, 125 lb., 4"	6.0	EA	133.01	1,225.00				1,358.01	8,148
	15110600 - Valves, Semi-Steel									
7030	Valves, semi-steel, lubricated plug valve, flanged, 200 lb., 4"	9.0	EA	443.96	385.00				828.96	7,461

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	Building Services Piping Total									**19,809**
	15200 - Process Piping									
	15200032 - Flanges, Ductile Iron									
0060	Stl ftg, gskt & bolt set, 150#, 4" pipe	18.0	each	87.74	8.70				96.44	1,736
	15200045 - Pipe, Fiberglass Reinforced (FRP)									
B84Y	Odor control, piping allowance	1.0	ea	2,632.20	4,500.00				7,132.20	7,132
	15200165 - Pipe, Glass Lined Ductile Iron									
0020	Piping, DI, glass lined, CL 50, 4" dia	260.0	lnft	13.31	37.98		2.25		53.54	13,921
	15200170 - Fittings, Glass Lined Ductile Iron									
0070	Fitting, DI, glass lined, 90 deg ell,4" dia	23.0	each	135.32	167.00				302.32	6,953
0200	Fitting, DI, glass lined, tee, 4" dia	5.0	each	202.90	231.23				434.14	2,171
	15200212 - Pipe, 316 Stainless Steel									
0150	Pipe, SS, A778, weld, Sched. 10S, type 316L, 4" dia.	30.0	lnft	26.67	16.64		0.67		43.99	1,320
	15200330 - Flexible Connectors									
301	Connectors, flex, dismantling Joint, 4"	4.0	each	197.41	573.57				770.99	3,084
	Process Piping Total									**36,317**
	15700 - Heating/Ventilating/Air Conditioning Equipment									
	15760250 - Electric Heating									
4050	Electric heating, heat trace system, 400 degree, 115 V, 10 watts per L.F.	260.0	LF	1.09	7.35				8.44	2,193
	Heating/Ventilating/Air Conditioning Equipment Total									**2,193**
	15950 - Testing/Adjusting/Balancing									
	15955700 - Piping, Testing									
0160	Pipe testing, nondestructive hydraulic pressure test	3.0	EA	875.78					875.78	2,627
	Testing/Adjusting/Balancing Total									**2,627**

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	05 - ELECTRICAL/INSTRUMENTATION									**193,700**
	16000 - Electrical and Instrumentation									
	16000000 - Electrical and Instrumentation									
0001	Electrical and Instrumentation Subcontract	1.0	lsum			193,700.00			193,700.00	193,700
	Electrical and Instrumentation Total									**193,700**

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Item	Item Description	Qty	Unit	Labor $/ Unit	Materials $/Unit	Subs $/Unit	Equip $/Unit	Other $/Unit	Total $/Unit	Total Net Cost $
	Grand Total									**2,053,911**

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Category	Percent	Amount	Hours
PILOT FACILITY (UNIT 1) Totals			
Labor	**9.96 %**	**204,500**	**3,370.2**
Material	**13.26 %**	**272,312**	
Subcontractor	**3.61 %**	**74,200**	
Equipment	**0.87 %**	**17,794**	**396.4**
Other	**0.00 %**	**1**	
User			
Net Costs		**568,807**	
Labor Mark-up	8.00 %	16,360	
Material/Process Equipment Mark-up	8.00 %	21,785	
Construction Equipment Mark-up	8.00 %	1,424	
Subcontractor Mark-up	5.00 %	3,710	
Sales tax	9.50 %	27,560	
Material Shipping & Handling	2.00 %	3,828	
Subtotal		**643,474**	
Contractor General Conditions	10.00 %	64,347	
Subtotal		**707,822**	
Start-up, training, O & M	2.00 %	5,032	
Subtotal		**712,854**	
Construction Contingency	25.00 %	178,213	
Subtotal		**891,067**	
Bldg Risk, Liability Auto Ins.	2.00 %	17,821	
Subtotal		**908,889**	

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Category	Percent	Amount	Hours
Bonds	1.50 %	13,633	
Subtotal		**922,522**	
Total PILOT FACILITY (UNIT 1)		**922,522**	
SECOND EXPANSION (UNITS 2 THROUGH 4) Totals			
Labor	**19.20 %**	**394,292**	**6,583.4**
Material	**42.36 %**	**870,061**	
Subcontractor	**9.43 %**	**193,700**	
Equipment	**1.32 %**	**27,050**	**601.5**
Other			
User			
Net Costs		**1,485,104**	
Labor Mark-up	8.00 %	31,543	
Material/Process Equipment Mark-up	8.00 %	69,605	
Construction Equipment Mark-up	8.00 %	2,164	
Subcontractor Mark-up	5.00 %	9,685	
Sales tax	9.50 %	85,226	
Material Shipping & Handling	2.00 %	14,310	
Subtotal		**1,697,637**	
Contractor General Conditions	10.00 %	169,764	
Subtotal		**1,867,401**	
Start-up, training, O & M	2.00 %	18,811	
Subtotal		**1,886,212**	

KING COUNTY
GREASE FACILITY
CONCEPTUAL ESTIMATE

Category	Percent	Amount	Hours
Construction Contingency	25.00 %	471,553	
Subtotal		**2,357,764**	
Bldg Risk, Liability Auto Ins.	2.00 %	47,155	
Subtotal		**2,404,920**	
Bonds	1.50 %	36,074	
Subtotal		**2,440,994**	
Total SECOND EXPANSION (UNITS 2 THROUGH 4)		**2,440,994**	

Attachment C: King County Review Comments

Review Comment Documentation Form
South Plant Grease Co-Digestion Study

Document: Tech Memo #2 Date: 7/7/2011 Comments Due: December 7th

Section	Page	Comment	Reviewer	Response	Responder
General	All	Replace “pilot” with “demonstration” throughout document when referring to the initial facility phase.	Smyth	Replaced	Muller
2	1	2nd sentence – replace the end of sentence starting with “while maintaining the land…” and replace with “without negatively impacting plant operations and biosolids management”.	Smyth	Changed	Mulller
2.1	1	1st bullet, 1st sentence – insert “target” (or other qualifier) ahead of “maximum fraction of VS…”	Smyth	Changed	Muller
2.1	1	2nd bullet, 3rd sentence – replace “pre-direction” with “practice”.	Smyth	Changed	Muller
2.1	1	1st para after bullets, 2nd sentence – replace “County and Brown and Caldwell” with “project team”	Smyth	Changed	Muller
2.1	1	Max. allowable HRT is based upon 3 digesters in service, not 4. Just to acknowledge this. Could confuse people if they don’t know the design. Unless there is the ability to de-rate grease facility when a digester is out of service and re-rate when all are in service. Same goes for Vol. Solids Loading rate.	Steinke	Added text	Muller
2.1	1	1st para after bullets, last 2 sentences – replace with “The data from the demonstration facility would be used to evaluate the potential expansion of the grease receiving facility to its optimum capacity at a future date (with the demonstration facility being integrated into the full facility). For the purpose of this evaluation it was assumed that the expanded facility would be sized to provide sufficient grease to the digesters to equal 30 percent of the average daily wastewater volatile solids load.	Smyth	Change made	Muller

Review Comment Documentation Form
South Plant Grease Co-Digestion Study

Document: Tech Memo #2 Date: 7/7/2011 Comments Due: December 7th

2.1.2	2	Not clear why we picked 4.6% -- number doesn't appear in Table 3-1 and isn't the midpoint between "4 to 5 percent range". Where did it come from?	Smyth	Assumed value based on table in TM-1. Added additional information on local market, large hauler who thickens/dewaters grease prior to disposal. The value used was an assumed value in the absence of testing.	Muller
2.1.3	2	Last paragraph, first sentence – delete "pilot facility operation, or prior to detailed"	Smyth	Deleted	Muller
2.2	2	All lines should be glassed lined or like material to reduce/eliminate grease build up.	Steinke	Added sentence noting the need for glass lining and or similar material to reduce maintenance from fouling	Muller
2.2	3	1st para after bullets – delete first sentence starting with "Brown and Caldwell and…"	Smyth	Deleted	Muller
2.2	4	1st full sentence – replace "Based on County preferences" with "The project team evaluated the"; replace "the County" with "and".	Smyth	Changed	Muller
Figure 2-5a	7	Tie-in location should be moved to digester equipment room. Because of the permanence of the pilot/demonstration design it should be design to go to the permanent or final location. Otherwise the cost will be prohibitive if the facility is never expanded but the pilot/demonstration is kept operating.	Steinke	Added text keeping the concept of using the THS lines if raw sludge preheating is implemented but stated the team decided to tie in at the digested sludge recirculation lines for the conceptual design. Preserved the figures with the modified text.	Muller
Figure 2-11	11	Text in figure is illegible. Need to show pump between scum removal and digester feed pump??	Smyth	Increased font size	Muller
Fig. 2-11	11	The process diagram should be modified by: 1. Moving the screen to after the heated storage/recirc. tank. Otherwise the coagulant grease will blind the screen constantly. 2. Truck should discharge directly into tank. Can provide air to pressurize vessel for offloading. Eliminates need for sump, sump pump, level	Steinke	Changed process flow diagram, assumed direct discharge to tank, a sump may be needed depending on truck type. The type of truck used by haulers should be verified during detailed design. This process flow model was placed into the report as an alternative to be assessed during detailed design, for both technical and capital improvements. The existing	Muller

Review Comment Documentation Form
South Plant Grease Co-Digestion Study

Document: Tech Memo #2 Date: 7/7/2011 Comments Due: December 7th

		control, cleaning, odor control ducting, etc.		facility design was maintain as it was thought to be more capital intensive.	
2.3.1.4	10	What is the recommended tank geometry?	PJS	Circular tank with a cone bottom was used in this analysis	Muller
2.3.2	11	Will the grease be heated prior to screening?	PJS	Changed the configuration to heat the unscreened grease in the storage tank prior to screening.	Muller
2.3.2.2	13	Wemco Hydrastahl – screenings pump could be used in this capacity. Standardization and spare parts. Why is a chopper pump necessary when you have screening? In the other BG applications it is needed for downstream equipment. In this case the screen provides that benefit.	Steinke	Added a note in the text to indicating the WEMCO as a possible candidate technology to evaluate in either detailed design or during demonstration testing.	Muller
2.3.2.2	13	1st sentence – delete “s” in “pumps”	Smyth	changed	Muller
2.3.2.3	13	Progressive cavity pumps – again would standardize on a pump in South plant for spare parts availability. Speeds are adjustable.	Steinke	Added a sentence recommending standardization when possible to reduce maintenance costs and training time.	Muller
Table 2-3	14	Shouldn’t the “Pump technology” to convey grease to the holding tank in the full build-out scenario be a chopper pump (unless new screening location makes a difference)?	Smyth	Typo, carry over from older table format, should be conveying from storage to grease thickener	Muller
2.3.2.4	14	Storage tank should be lined for both odor control and to eliminate grease buildup on tank walls.	Steinke	Comment added to the text	Muller
2.3.2.4	14	Storage tank volumes seem to be larger than needed. The pilot HLR is 31,000 gpd and the tank is designed to hold that volume. The facility is designed to continually discharge material and it would seem that decreasing the volume would decrease construction and operating costs. Heat loss in that large of tank. Might not get perfect discharge flow rate but reduce costs.	Steinke	The system could be smaller assuming constant discharge. The system was sized to hold the full volume because we did not have a feel for the peaking of truck traffic through out the day. I agree that this should be addressed in the detailed design phase as a refinement especially if market conditions could be further defined prior to design.	Muller
2.3.2.8	16	1st para, last sentence – replace “will be” with “should be”.	Smyth	Changed	Muller

Review Comment Documentation Form
South Plant Grease Co-Digestion Study

Document: Tech Memo #2 Date: 7/7/2011 Comments Due: December 7th

2.3.2.8	16	2nd para – modify to reflect discussion at workshop -- concern regarding moisture carrying over to carbon.	Smyth		
Figure 2-14	17	Too many screens. Only have 3 screens in plant to treat 115 AWWF. Need to reduce number. Larger screen. Need to oversize pilot so it can be used in conjunction with another in expanded facility. Only have 2 screens. Less equipment to maintain.	Steinke	We agree that the number of screens could be reduced based on the discussions in the meeting. We have left the initial configuration in the report as it is more conservative in the business case evaluation but this would be a great value engineering change to the project.	Muller
Fig. 2-14	17	Only like 2 tank approach if thickener is installed and then one tank for raw product and 2nd tank for thickened material. Need ability to reconfigure tanks if expanding from pilot to expanded facility.	Steinke	A reconfiguration to the suggested model could be done as part of a detailed design. The scum concentrator has a 1000 gallon storage tank on it for thickened grease and is heated. The existing storage tanks could be used to meter the grease to the thickener rather than a dedicated thickened grease storage tank. I would be little concerned about trying to mix the grease effectively in a thickened grease storage tank in order to maintain temperature. A dedicated tank could be explored or the storage hopper on the concentrator expanded. Given the impact of the added tank to the equipment layout and costs it was not added at this time.	Muller
3	18	1st sentence – replace "BCE" with "Business Case Evaluation (BCE)"	Smyth	Changed	Muller
3.2	18	1st para, 3rd sentence – replace "on grease" with "of grease".	Smyth	Changed	Muller
Table 3-1	19	Replace "Data" with "Full Buildout"	Smyth	Changed	Muller
3.4.1	19	Adjust labor rate per input at workshop	Smyth	Changed	
3.4.1	19	Labor should be $48.10/hr.	Steinke	Done	Muller
3.4.1	19	How often will the equipment need to be cleaned and inspected?	PJS	The maintenance associated with the equipment will likely be impacted by the quality of the material collected along with configuration of equipment. The	

Review Comment Documentation Form
South Plant Grease Co-Digestion Study

Document: Tech Memo #2 Date: 7/7/2011 Comments Due: December 7th

				degree of contamination from hauler picking up foreign objects will be area specific. Some have more some have less. Some reductions can be made by requiring the clean out of trucks or only collecting grease in specific trucks. The demonstration facility will likely address this issue. We would want to design the facility with as much automation as possible reducing operator attention to the facility.	
3.4.2	19	Even though it will use the plant heat system to heat grease it would be good to know the energy demand for the tube in tube heat exchanger. Will use energy that won't be available for sale to PSE.	Steinke	I have added the net biogas available to PSE, accounting for grease heating and the Binax process efficiency.	Muller
Table 3-2	20	Provide "Total" for annual electricity cost.	Smyth	Added	Muller
3.4.4.	20-21	Need to have some rebuild costs, not just replacement costs in estimate. We have lots of equipment that is rebuilt at a much higher frequency than replaced.	Steinke	For this level of analysis the repair and replacement costs are assumed to be sufficient.	Muller
3.4.6	21	1st sentence – add "will likely" after "TM-1".	Smyth	Added	Muller
3.4.6	21	2nd para.—concentration of BOD should be rounded off to reflect precision of estimate – say, 22,000 mg/l?	Smyth	Changed	
3.4.6	21	Based upon John's comments and observations the scum thickener will not pencil out cost wise. This will then limit the amount Hydraulically that can be accepted. Does the facility then get resized to reflect this new paradigm.	Steinke	If the thickener is not used then the facility will become hydraulically limited and we would likely have to resize the facility based on that limit rather than the organic loading limit used in the current estimate.	Muller
3.4.6	22	2nd para, -- should note that cost could be reduced by only operating the settler when one digester is out of service.	Smyth	I agree, and some text was added noting that this could be a refinement in detailed design	Muller
3.4.7	22	Based on budget estimates, the average cost of biosolids haul & application is projected to be $39/ton in 2012.	Smyth	Noted and adjusted in BCE as well as text.	Muller

Review Comment Documentation Form
South Plant Grease Co-Digestion Study

Document: Tech Memo #2 Date: 7/7/2011 Comments Due: December 7th

3.4.7	22	Dewatering polymer usage is around 38 lbs. active /DT. The cost is around $1.05/lbs. With an activity around 41.5%. This to be added to costs to treat.	Steinke	This turned out to be a significant added cost to the project and was added to the BCE. It was assumed that the $/lb cost for polymer was on a whole polymer basis and not active polymer cost	Muller
3.5.3	23	Based on budget estimates, the revenue from biosolids fertilizer value is projected to be $1.48/wet ton in 2012. Suggest using $1.50/wet ton.	Smyth	Values adjusted in the BCE model and text was updated to reflect the new values.	Muller
New Table 3-5	23	I think we need a new table that summarizes the cost items/total and revenue items/total (using $0.05/gallon tip fee). Feel free to qualify with +/- range, etc. so everyone knows we're working with a lot of not-so-well-defined variables.	Smyth	I added a table showing the escalated 20 year costs and revenues.	Muller
Figure 3-1	25	Can we get a similar graphic that shows the annual net revenue/cost for each grease load/tipping fee scenario? Don't bust the budget with this – if it's time consuming, I can do it on my own. I think it might be easier for decision-makers to grasp.	Smyth	I reproduced the graph of the variation in tipping fees and grease loads to the build out facility (the same graph we made for the pilot). It shows very similar trends as the pilot. The graph was inserted into the document.	Muller
General Equipment comment		I would try and design around some of the equipment we use in the facility to ensure spares are on shelf. Screen, Wemco Hydrostahl, progressive cavity pump, etc. Might be a little oversized for facility but eliminate need for spare parts, and could be run at slower speeds.	Steinke	I agree and have placed several comments within the text suggesting common equipment for detailed design. This could lower operating costs long-term.	Muller
General		Due to the facility is more permanent than pilot/demonstration what happens if a piece of equipment goes down? Pilot wouldn't have spares, nor redundancy. In pilot/demonstration there is no redundancy will there be spares? If it breaks do we put up sign Not receiving BG until repairs are completed? Spare parts can take 4-6 weeks to receive. See it all the time.	Steinke	The need for redundancy was not addressed in the demonstration facility as it was assumed it would initially be accessed by a limited number of haulers. But if the facility were to not be expanded this could be an issue that needs to be addressed in detailed design. The standardization of equipment should help with this but fully redundant critical	Muller

Review Comment Documentation Form
South Plant Grease Co-Digestion Study

Document: Tech Memo #2 Date: 7/7/2011 Comments Due: December 7th

				equipment may need to be purchased or full sets of spare parts included as part of the procurement. At this planning level this could be addressed in the capital cost range provided on the estimate.	
General		Some large costs are not included in full facility costs (i.e. WBG, scrubbed gas system upgrade, etc.). Need to be included somewhere.	Steinke	I agree with this, as these costs and impact the overall viability of the project. However given the current fluidity in some of the numbers it would require a more detailed effort to associate these upgrades with specific design conditions. A BCE similar to the one used in this analysis could be used to identify the best grease facility size based on additional upgrades needed or avoided. As a next step these costs should be developed and an understanding of their impact on project viability as well as determine if an incremental cost should be incurred rather than the full cost burden on the project as conventional operations may gain a benefit from these upgrades.	Muller
General Comment		A market study should be performed to determine how haulers currently are disposing or reusing BG, how much they are treating, what their costs are to determine a tipping fee structure, then use this data to more accurately set size of facility and cost/benefit.	Steinke	I agree with this. This will really help define many of the design parameters and assumptions. A market assessment is a good way to define the project boundary conditions.	Muller
General		If a situation arise where grease cannot be fed to the digester (process upset, equipment problem, etc), how long can the grease be stored before going bad.	PJS	I don't know of any data existing on this subject, but I would suspect that the grease will be okay for an extended period. This is based on the age of grease in the interceptors prior to collection. Many municipalities require quarterly collection of grease which is a great substrate. I would suspect that you may want to dispose of the grease if it exceeds	Muller

Review Comment Documentation Form
South Plant Grease Co-Digestion Study

Document: Tech Memo #2 Date: 7/7/2011 Comments Due: December 7th

				several months of storage as it will be come a resource drain to manage. It maybe worth the effort to calculate the operating demands of the grease against its revenue potential to determine the maximum hold time before it becomes cheaper to landfill it.	
General		If grease cannot be fed for an extended period of time, how do we dispose of the grease?	PJS	You could contract with a hauler to have them take it off and dispose of it. Depending on the configuration of the final system you could dewater/thicken it and landfill the material. It would need to pass a paint filter test as well as meet other regulatory requirements. If you were able to process the grease it would be possible to transport the heated and cleaned grease to another KC facility to digest it on a temporary basis. It would be an added cost but may work as an outlet in an emergency or cost savings approach.	Muller

Review Comment Documentation Form
South Plant Grease Co-Digestion Study

Document: Tech Memo #2 Date ____________________ Comments Due: December 7th

Section	Page	Comment	Reviewer	Response	Responder
3.2 Biogas Production		Add a statement to the effect that – though the gas scrubbing system has a total capacity sufficient to scrub all the gas that would be produced from the 30% VS loading, the a) limited equipment redundancy (e.g., capacity of the gas compressors is 2 small units and one large), b) their age and reliability (e.g., the gas compressors require frequent maintenance), and c) the tighter gas specs for the scrubbed gas to be sold to PSE, will notably reduce the volume of additional scrubbed gas that can be sold to PSE.	Butler	A good point. I have added the language into the report. This along with other capital improvements needs to be evaluated to limit bottle necks which impacting overall program viability.	Muller
2.3.2.1	12	Further emphasize the fact that there is little if any experience or information available on which screening technology or design setup works or will work better than another.	Butler	I added some text stating significant attention is needed in the selection of this equipment.	Muller
2.3.2.8		I'd prefer to NOT use the bioscrubber-carbon in-series design as the model for odor control for the full scale design. We have had repeated issues with fouling of carbon that is downstream of wet scrubbers due to failure of the moisture removal systems. The carbon system quickly crust over with moisture carryover. I anticipate we can/will have similar issues with a bioscrubber-carbon design since the air from the bioscrubber should be saturated with water. So I'd propose we adopt a caustic carbon-virgin carbon in-series design as the model for the full scale design until we have more information on resolving moisture issues.	Butler	I have added some text stating the need for detailed analysis on the odor control system for its effectiveness and reliability in this type of service. However changing the system out completely will not have a significant impact on the analysis of this report. The cost estimate and facility layouts were not changed for this reason	Muller
Table 3-1		For the row titled "Data", I assume this row is to be titled "Expansion to full capacity" or something to that effect.	Butler	Change made	Muller
3.4.1		Instead of calculating or showing FTEs for Labor requirements, I'd prefer to show or	Butler	I made the requested change. This approach provides more information	Muller

Review Comment Documentation Form
South Plant Grease Co-Digestion Study

Document: Tech Memo #2 Date ____________________ Comments Due: December 7th

		calculate the number of "labor hours" or "staff hours". For example, in the first sent., we can change "additional staffing" to "additional labor hours". The 3rd Sent. would read something more like "… it was assumed that about 4500 labor hours per year would be required to…" Then you can add a sentence to the effect that "the equivalent FTEs required for this work needs to also consider additional employee time such as holidays, vacations, training, etc.. When these times are considered as a whole, the equivalent FTEs required to support this work is about 2.5-FTEs (or whatever it is).		regarding how the County may want to staff the facility	
3.4.5		I think we can assume the labor cost for biogas treatment is already covered (and thus should be 0.00), or fairly minimal to reflect an increase in maintenance of the scrubbing system because it is handling more gas (so maybe assume something like 0.02 – but not 0.1). I can support using 0 for this cost.	Butler	I reduced the labor rate to 0.02 $/therm in the business case evaluation. It had a noticeable impact on the overall project NPV.	Muller
3.5.3		I have this feeling that the annual check for the Nitrogen content of all WTD's biosolids is around $100k or so. You may want to check that out and relook at the $150k estimate for the grease waste.	Butler	Different evaluation criteria were provided by John Smyth. It reduced the net benefit to approximately $16,500 annually.	Muller
3.6		Suggest adding a bullet regarding "Nitrogen Recycle and Nitrogen Removal" and the fact that N loading on the secondary system will increase due to the additional organic loading on the digesters from the brown grease. Of course, this increase in N recycle loads would be no different than if the additional organic loading was due to system growth. We just need to be aware of the additional recycle load if/when effluent N limits come to pass.	Butler	I added some text recommending the exploration of different treatment alternatives for the added nitrogen load to the plant from FOG co-digestion.	Muller

Review Comment Documentation Form
South Plant Grease Co-Digestion Study

Document: Tech Memo #2 Date ____________________ Comments Due: December 7th

Annual Cost Estimates		Annual dewatering polymer costs can be estimated assuming 38 pounds-active polymer is used per dry ton (2000-lb) of biosolids hauled, and assuming polymer costs $1.15/lb of emulsion and the emulsion contains 41.5% active polymer. The annual cost for dewatering polymer will be in the $200k/yr range.	Butler	I calculated this based on values provided by Curtis Steinke, similar numbers to that which you provided except the cost was 1.05 $/lb. This produced a value around $229K per year in polymer, which was added to the BCE.	Muller
Annual Cost Estimates		Let's not assume we will achieve a full annual supply of brown grease to achieve the 30% load that the design is based on. We need to either use a range or something closer to 70-80% as our best scenario.	Butler	I agree. Without a thorough vetting of market conditions and process equipment there is a risk that the facility is oversized and/or will not receive the design quantities of grease. I have added a sensitivity analysis, leaving the facility as designed and looked at the impact of reduced loadings of grease to the plant to simulate a smaller than expected market or the imposition of an internal program limit. It looks like the break point is about 45% of design load. Text and figure added to the TM.	Muller
Annual Cost Estimates		In description about the cost estimate, please be sure to note that the full-scale cost estimate has (or has not) accounted for such factors as security, traffic control, data/scale management by doing ….	Butler	Instrumentation and control was assumed to contain the needed security apparatus. The cost estimate for this analysis used a lump sum for instrumentation and controls, due the lack of engineering definition.	Muller
Annual Cost Estimates		Just want to make sure we are clear that the capital investment cost estimate is the overall project cost as King County defines it.	Butler	I have added in the allied costs at a rate of 45 percent, excluding contractor contingency and sales tax.	Muller